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ABSTRACT

This technical specialty course is one of thirty-five courses designed for use by two-year postsecondary institutions in five nuclear technician curriculum areas: (1) radiation protection technician, (2) nuclear instrumentation and control technician, (3) nuclear materials processing technician, (4) nuclear quality-assurance/quality-control technician, and (5) nuclear reactor (plant) operator trainee. This course, Radiological Emergencies, contains seven modules: General Procedure for Radiological Emergencies, Emergency Equipment for Nuclear Facilities, Surface Contamination-Decontamination, Criticality Control, Control of Radiological Hazards, Emergency Planning for Nuclear Facilities, and Emergency Drills for Nuclear Facilities. Each module follows a typical format including the following sections: introduction, module prerequisites, objectives, subject matter materials, and tests. (A master index and suggested program planning guides are also available--see CE 026 856 and CE 026 639-643.) (LRA)

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ED192100

Nuclear Technology Series

COURSE 18

RADIOLOGICAL EMERGENCIES

CENTER FOR OCCUPATIONAL RESEARCH
AND DEVELOPMENT
4800 LAKEWOOD DRIVE
WACO, TEXAS 76710

AUG 1980

CE 026 658

U S DEPARTMENT OF HEALTH
EDUCATION & WELFARE
NATIONAL INSTITUTE OF
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PREFACE

ABOUT NUCLEAR TECHNOLOGY MODULES

The modules - developed for use in two-year postsecondary technical institutions to prepare technicians for employment - are useful in industry for updating employees in company-sponsored training, and as laboratory texts in engineering schools. The principles, techniques and skills taught in the modules, based on tasks that nuclear technicians perform, were obtained from a nationwide advisory committee of employers of nuclear technicians. Each module was written by a working technical expert/experienced writer team and tested with students.

A module contains the following elements:

Introduction, which identifies the topic and often includes a rationale for studying the material.

Module Prerequisites, which identify the material a student should be familiar with before studying the module.

Objectives, which clearly identify what the student is expected to know for satisfactory module completion. The objectives, stated in terms of action-oriented behaviors, include such action words as operate, measure, calculate, identify and define, rather than words with many interpretations, such as know, understand, learn and appreciate.

Subject Matter, which presents the background theory and techniques supportive to the objectives of the module. Subject matter is written with the technical student in mind.

Exercises, which provide practical problems to which the student can apply this new knowledge.

Materials, which identify the equipment required to complete the laboratory procedure.

Procedures, which is the experiment section, or "hands-on" portion of the module (including step-by-step instruction) designed to reinforce student learning.

Data Tables, which are included in most modules for the first year (or basic) courses to help the student learn how to collect and organize data.

Reference Materials, which are included as suggestions for supplementary reading/viewing for the student.

Test, which measures the student's achievement of the prestated objectives.

A helpful Index has been added at the end of each course.

The materials contained herein were developed pursuant to a contract with the Office of Education, U.S. Department of Health, Education and Welfare: Contract No. 300780582. Contractors undertaking such projects under Government sponsorship are encouraged to express freely their professional judgment in the conduct of the project. Points of view or opinions stated do not, therefore, necessarily represent official Office of Education position or policy.

The Nuclear Technology Series consists of five curricula:

Nuclear Reactor (Plant) Operator Trainee.
Radiation Protection Technician.
Nuclear Materials Processing Technician.
Nuclear Quality-Assurance/Quality-Control Technician.
Nuclear Instrumentation and Control Technician.

The completed Nuclear Technology Series consists of the following 35 technical specialty courses:

Radiation Physics.
Radiation Protection I.
Principles of Process Instrumentation.
Heat Transfer and Fluid Flow.
Introduction to Nuclear Systems.
Instrumentation and Control of Reactors and Plant Systems.
Reactor Operations.
Reactor Safety.
Reactor Auxiliary Systems.
Power Plant Systems.
Radiation Detection and Measurement.
Reactor Physics.
Power Plant Chemistry.
Introduction to Quality Assurance/Quality Control.
Metallurgy and Metals Properties.
Mechanical Component Characteristics and Specifications.
Radiation Protection II.
Radiological Emergencies.
Radiation Shielding.
Radiation Monitoring Techniques (Radiochemical).
Radioactive Materials Disposal and Management.
Advanced Radionuclide Analysis.
Nuclear Chemical Processes.
Nuclear Systems and Safety.
Radioactive Material Handling Techniques.
Nondestructive Examination (NDE) Techniques I.
Metrology.
Welding Inspection.
Civil/Structural Inspection.
Mechanical Inspection.
Quality-Assurance Practices.
Nondestructive Examination (NDE) Techniques II.
Control Systems I.
Control Systems II.
Power Plant Electrical Systems and Components.

Availability: Instructional modules are available individually or by courses from:

Center for Occupational Research and Development
4800 Lakewood Drive, Suite 5
Waco, Texas 76710
Telephone (817) 772-8756

Printed:

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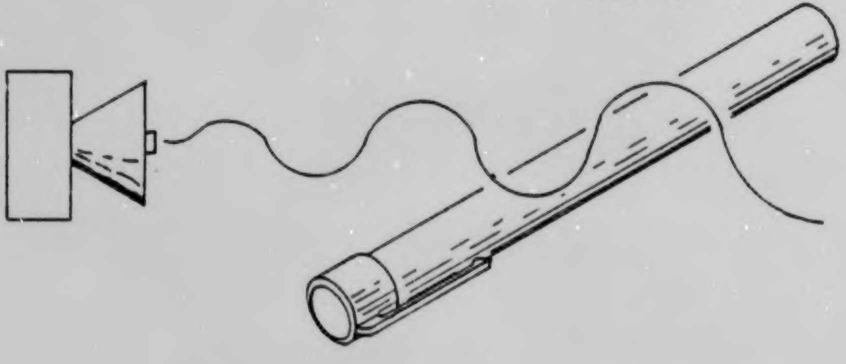
NUCLEAR TECHNOLOGY

MODULE 18 - 1

GENERAL PROCEDURES FOR RADIOLOGICAL EMERGENCIES

RADIOLOGICAL
EMERGENCIES

COURSE 18



CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

COURSE 18 RADIOLOGICAL EMERGENCIES

⇨ Module 18-1	General Procedure for Radiological Emergencies
Module 18-2	Emergency Equipment for Nuclear Facilities
Module 18-3	Surface Contamination – Decontamination
Module 18-4	Criticality Control
Module 18-5	Control of Radiological Hazards
Module 18-6	Emergency Planning for Nuclear Facilities
Module 18-7	Emergency Drills for Nuclear Facilities

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INTRODUCTION

Radiological emergencies can occur at any time or place at which radioactive materials or radiation-producing devices are used, stored, or transported. To cope with these emergency situations, licensees are responsible for the planning and implementation of emergency procedures. In order to be effective, these procedures must encompass a broad spectrum of accidents and be addressed to mitigation of the emergency consequences. The value of a well-defined plan of action through which to cope with a radiation accident must not be overlooked, because such a plan provides the licensee with protection against unnecessary risk to personnel and minimizes the hazards that could jeopardize the health and safety of the public.

This course of instruction addresses radiological emergencies, whose assessment and classifications are an integral part of the combinative plan for the handling of such emergencies. This first module serves as an introduction to the course and discusses the development of emergency plans and procedures. It presents information that pertains to emergency classifications and the methods by which each type of emergency is handled.

MODULE PREREQUISITES

The student should have completed Course 1, "Radiation Physics"; Course 2, "Radiation Protection I"; Course 11, "Radiation Detection and Measurement"; and Course 17, "Radiation Protection II."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Identify the five emergency classifications, and describe the correct response to each classification.
2. Describe the principles of radiological emergency planning and the information required for the development of implementation procedures.
3. Elaborate on the types of radiological emergencies that have occurred.

STEPS IN THE DEVELOPMENT OF THE EMERGENCY PLAN

The single most important phase of emergency planning is the preparation of a plan of action to be followed in the event that a radiological emergency occurs. Planning ahead will minimize, if not eliminate, the surprises one might encounter when the emergency occurs. Development of this plan of action before the emergency occurs could be described as "pre-emergency planning" and begins with the compilation of background information. Background information includes the development of a working knowledge of radiation and radioactivity including the potential hazards of radioactive materials and the basic principles of radiation protection.

The emergency plan should address the problem of how the consequences of a radiological emergency can be mitigated. It should provide for corrective actions that can and will be taken to protect the radiation worker, prevent damage to property, and eliminate or minimize hazards that could jeopardize the health and safety of the public.

As indicated by Figure 18-1-1, the steps in emergency-plan development are as follows:

- Appointment of the emergency organization.
- Gathering of information.
- Identification of problems.
- Evaluation of potential problems and associated hazards.
- Development of the plan.

These steps are explained in more detail in the discussion that follows.

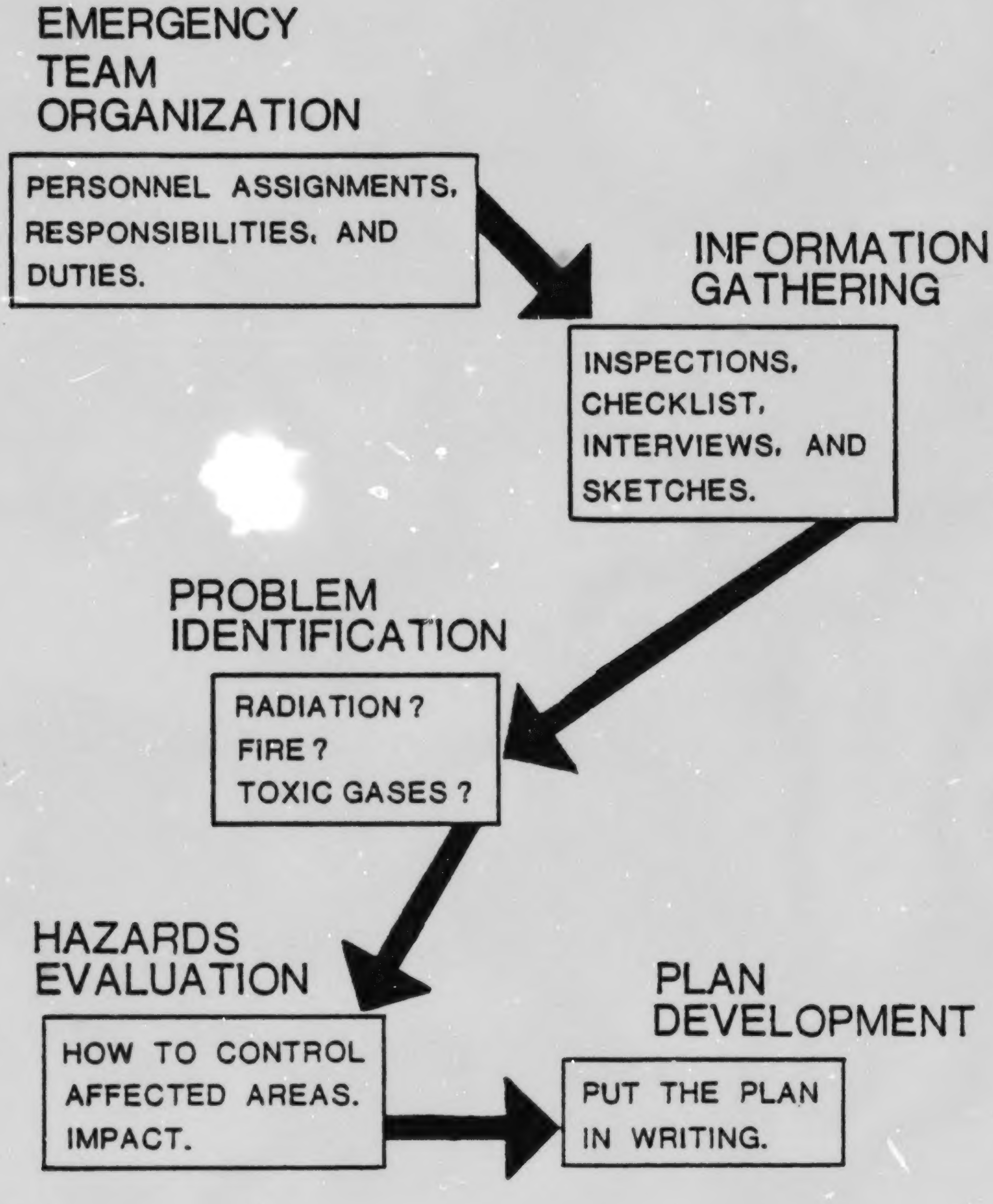

EMERGENCY TEAM ORGANIZATION
PERSONNEL ASSIGNMENTS, RESPONSIBILITIES, AND DUTIES.
INFORMATION GATHERING
INSPECTIONS, CHECKLIST, INTERVIEWS, AND SKETCHES.
PROBLEM IDENTIFICATION
RADIATION ?
FIRE ?
TOXIC GASES ?
HAZARDS EVALUATION
HOW TO CONTROL AFFECTED AREAS. IMPACT.
PLAN DEVELOPMENT
PUT THE PLAN IN WRITING.

Figure 18-1-1. The steps of emergency planning.

APPOINTMENT OF THE EMERGENCY ORGANIZATION

Development of the emergency plan begins with the process of determining what is to be done within a broad spectrum of emergency circumstances and situations. The plan must include the emergency organization and must outline the areas of responsibility of assigned personnel. The plan then should take a general approach that covers the potential emergency problems and other incidents that affect the normal operation of this facility. Because the plan is only a plan, it must possess sufficient flexibility to allow the emergency team leader on duty at the time of the emergency the latitude to make appropriate decisions.

THE GATHERING OF INFORMATION

The next step explained in this module is the collection of information about the facility or specific installation. This phase requires a detailed study of the facility layout and floor plans, physical inspection of the premises, discussions with management and key personnel who are knowledgeable about the activities conducted in the individual areas, and finally preparation of a record that contains all the gathered information. The validity of this information-gathering process can be enhanced by use of an inspection checklist. Table 18-1-1 contains a suggested method that may be helpful in the gathering of necessary information.

TABLE 18-1-1. CHECKLIST FOR THE INVENTORY AND ASSESSMENT OF FACILITY LAYOUT AND ACTIVITIES CONDUCTED FOR EMERGENCY PLANNING.

1. Installation Layout.
   - Boundary fences.
   - Show location of access roads and entrance gates on sketches.
   - Normal traffic and emergency access routes to each building illustrated on sketches.
   - Single- or multi-floor structure?
   - Outside access to 2nd, 3rd, 4th, ... floor levels? If so, show on sketch.
   - Does building contain radioactive materials? If so, on the sketch code the building with a bright color (e.g., yellow).
   - Identify all buildings that contain fire-protection systems.
2. Storage Facilities.
   - Combustible materials. Identify and show location on sketch. Include and identify all types of combustible materials (fuel, organic solvents, etc.).
   - Retention tanks and collection sumps for radioactive liquid materials.
     - Storage capacity?
     - Above ground?
     - Discharge route from tanks. Make sketch that shows location and method with which to intercept and recontain materials.
3. Emergency Generators.
   - Location and fuel type.
   - Areas and equipment served (e.g., ventilation and radioactivity monitoring systems in the radioactive waste storage and processing building).

- Means of actuating. Automatic? Manual?

4. Building Floor Plans.
   - Normal access routes.
   - Emergency exits.
   - Location of radioactive materials or radiation areas (including high radiation areas) if present.
   - Identification of heavy fire-loading areas (e.g., cardboard cartons, cleaning solvents, records storage).
   - Emergency showers. Type and locations.
5. Radioactive Materials.
   - Radioisotopes. Identify and list quantity in curies, millicuries, or microcuries and type of radiations emitted (e.g., alpha, beta, gamma, or neutrons or any combination thereof).
   - Special nuclear materials (fissile). Identify and list quantity in grams (e.g., ^{235}U, 13,440 grams contained in unirradiated reactor fuel elements and stored in fuel storage vault. (See Fuel Storage Building floor plan for vault location.)
   - Physical form of materials.
     - Gas.
     - Liquid.
     - Solid.
     - Powder or dust.
   - Containment.
     - Sealed sources.
     - Shielded container. List type of shielding materials (e.g., lead, concrete, steel, paraffin, etc.).
     - Glove boxes. Type of ventilation and location of filtering system.

- Radiation levels (mR/hr or R/hr).
  - At 3 feet from stored materials.
  - Entry points to the room or storage location.

6. Protective Equipment and Emergency Supplies.
   - Area radiation monitors at fixed locations with readouts in the emergency control center.
     - Spare bottles available (number and location).
     - House installed airline respirator system. Denote hookup points and length of hose.
     - Respirators (number, location, type, full-face or nose/mouth, and types of filters).
7. Ventilation Systems.
   - Location of fan rooms.
   - Interfaced with emergency generators.
   - Areas serviced by each fan in the system.
   - Location of ducts.
     - Incoming air.
     - Exhaust air.
   - Volume of each system in cubic feet per minute.
   - Type of system.
     - Recirculating.
     - One-pass-only (continuous exhaust of incoming air).
   - Filters. Prepare a detailed sketch that illustrates type of filter media, assembly, and locations.
   - Are ventilation systems interfaced with radiation monitoring systems that have shutdown capabilities?
   - Power supply and control. Location and accessibility for shutdown.
8. Area Radiation Monitors.
   - Type and range of detectors.
   - Location of each monitoring station.

- Are instrument readouts and alarms available at monitoring locations? Control room? Emergency control center?
- Portable radiation survey meters.
  - Type (GM, Ion-chamber, etc.).
  - Number of each type of instrument available.
  - Location of instruments.
  - Frequency of operability checks and calibrations.
- Protective clothing and equipment.
  - Booties or shoecovers (both low- and high-top styles).
  - Coveralls (quantity, location, and sizes available).
  - Headcovers (hospital surgeon's and winterhoods).
  - Gloves (rubber surgeon's, plastic, cotton, leather; and type – wrist or full arm).
  - Gloveliners.
  - Tape (plastic and masking, in various widths).
  - Plastic bags (30- to 55-gallon size).
  - Plastic sheeting (rolls of various widths).
  - Personnel dosimeters (direct and indirect reading). Denote frequency of operability checks and calibrations.
  - Rope and other types of barricading materials.
  - Warning signs, pencils, notepads, and clipboards.
  - Two-way radios (walkie-talkies). Denote the range of this communication system.
- Breathing apparatus.
  - Self-contained. Location and number available; frequency of inspections and test.
  - Demand.
  - Pressure-demand.

- Air or oxygen.
- Bottles (tanks). Compatible with local fire department equipment?
- Capabilities for refilling of bottles.
- Frequency of operability checks and calibrations.

9. Fire detection.

- Smoke detectors.
- Heat-sensitive detectors.
- Alarm notification in the control room? Emergency control center? Fire department command center (dispatcher), for both on-site and off-site fire departments?
- Prepare a map of the area protected by each detection system.
- Sprinklers and automatic fire-suppression systems.
    - Type (water, CO_2, etc.).
    - Location of control valves.
    - Prepare a map of area covered by each system.
    - Location of drain valves (water). Are drain valves connected to retention storage tanks for radioactive liquids?
    - Identification of any area not protected by fire-suppression systems.

10. Emergency Notification Roster.

- Names and phone numbers (home and office) of the following:
    - Facility management.
    - Health physics supervisors.
    - Radiation monitors.
    - Federal, state, and local regulatory and governmental agencies.
    - Fire departments.

- Ambulance service.
- Emergency medical assistance.
- Hospital and medical facilities.

IDENTIFICATION AND EVALUATION OF POTENTIAL EMERGENCY PROBLEMS

This phase of emergency planning involves the identification and evaluation of background information compiled from the facility inspection checklist. This evaluation must begin with the recognition of potential emergency problems and their associated hazards. It requires the identification of possible hazards to the emergency response personnel. It includes the determination of deviations from normal emergency operations that may be dictated by the presence of radioactive materials or high levels of radiation; for example, the recovery of analytical samples for determining radioactivity concentrations that may be located in an area surrounded by extremely high levels of radiation that could cause undue exposure risks to the personnel involved.

The different types of emergencies that could occur at the facility for which the emergency plan is to be developed must be analyzed. The emergency classification system should cover the complete spectrum of emergencies, ranging from minor occurrences to the most serious radiological accident.

Each class of emergency described should include a set of instructions that outline the immediate actions to be taken for coping with the emergency. An acceptable classification system consists of –

- Personnel emergency.
- Emergency alert.
- Reactor emergency.
- Facility or site emergency.
- General emergency.

A discussion of the emergencies that comprise this classification system is necessary at this point. NOTE: The classification system discussed here applies to reactor sites as well as to other applicable facilities.

Personnel Emergency

This class involves accidents or occurrences on-site in which emergency treatment of one or more individuals is required and includes those situations that have no potential for escalation to more severe emergency conditions. A personnel emergency would not be expected to activate an entire emergency organization, although it may require special local services such as ambulance and medical support.

Included in this emergency classification are injuries that may be complicated by radioactive contamination or by radiation exposures to employees and other on-site personnel. This class includes the subclasses of bodily injury without radioactive contamination or exposure and bodily injury with radioactive contamination or an exposure to radiation in excess of 25 Rem. Bodily injury without radiation hazards includes all accidents or injuries of the industrial type. Bodily injury with radiation hazards includes all industrial accidents or injuries in which radioactive contamination is associated with the injury or may have been present in the area at which the accident occurred. Personnel emergencies usually are handled by the supervisor on duty or a member of management. If bodily injury with radioactive contamination is involved, or if the accident has occurred in an area at which radioactive materials are present, the individual in charge must immediately contact the health physics personnel for assistance. Emergency medical treatment should be administered and the injured personnel moved to an area free of radiation hazards. The health physicist would conduct a detailed contamination survey and begin appropriate decontamination procedures. Decontamination procedures will be performed only as a secondary operation; the primary objective is the administration of the required emergency medical treatment. The individual in charge either shall summon, or direct others to summon, any additional medical assistance, such as ambulance services, emergency medical technicians, and a hospital that has agreed to provide medical services for radiological accidents.

Implementation of procedures for handling this class of emergency also may be incorporated into the radiation protection procedures and general safety procedures for the facility. The recognition of this class of emergency is primarily a judgment matter for supervisory personnel. Therefore, personnel emergencies are fixed in the classification system as those emergencies that are restricted in scope of involvement and that will not escalate to a more serious emergency of affect other facility operations.

Emergency Alert

This class involves specific situations (at a reactor or other facility site) that can be recognized as creating a hazard potential that previously was nonexistent or latent. The situation yet has not caused damage to the reactor or harm to personnel, but may warrant an immediate shutdown of the reactor if it is in an operating mode. In this situation time is available for precautionary and constructive steps that could prevent an accident or mitigate the consequences should it occur. Emergency alert situations may be brought on either by manmade, or by natural, phenomena.

Emergency alert conditions imply a rapid transition to a state of readiness by the emergency team and, possibly, by some off-site emergency support organizations; possible cessation of certain routine functions or activities not immediately essential; and possible precautionary actions that may be required by a specific situation. Examples of situations that should be placed in this class are threats to, or breaches of, security measures such as bomb threats or civil disturbances; several natural phenomena such as a flood, hurricane, or tornado in the facility environment; emergency situations such as nearby fires; or release of a toxic or noxious gas in or near the area. Either the supervisor on duty or a member of the facility management will direct the response for an emergency alert.

Reactor Emergency

This class includes those physical occurrences within the facility that require emergency organization response.

The initial assessment leading to this class should indicate that it is unlikely that an off-site hazard will be created; however, substantial modification of reactor operating status is a highly probable corrective action if the automatic protective systems already have not produced such action. Although this class is associated with a judgment that the emergency situation can be corrected and controlled by the on-site staff, notification through normal reporting mechanisms to an appropriate off-site agency to alert it as to the nature and possible extent of the incident should be a measure associated with this type of emergency. Protective evacuation or isolation of certain areas of the facility may be necessary; for example, incidents such as fires that may have a significant potential for triggering a release of radioactive materials to the off-site environment should require that the licensee notify the principal federal, state, and local governmental agencies of the plant's status. The licensee then would recommend that the pertinent off-site agencies, required to respond to a particular emergency, be contacted, apprised of the situation, and directed to assume an alert condition (short of mobilization) until further notice. The off-site agencies would be expected to remain in this condition either until the plant was verified to be in a safe condition or until one of the other emergency classification categories was indicated, possibly requiring further action by off-site emergency response personnel.

Situations that might fall into this class are those accidents that are predicted to have insufficient radiological consequences off-site to warrant taking protective measures. Fires and minor explosions (such as the failure of an experiment under pressure) in the facility should fall into this class of emergency.

Activation levels for declaration of reactor emergencies should be based upon the recognition of an immediate need to implement in-house emergency measures to protect or provide aid to affected persons, or to mitigate the consequences of damage to equipment, coupled with a positive observation that radiological monitors do not indicate the possibility of a more serious emergency.

Facility or Site Emergency

Because of measures taken to guard against their occurrence, emergency situations more severe than a reactor emergency are not expected to occur during the normal operations of the facility. Nevertheless, prudence and necessity require that facilities make provisions for a class that involves an uncontrolled release of radioactive materials into the air, water, or ground to an extent that the initial assessment indicates protective off-site action should be considered. The alerting of principal off-site emergency organizations is recommended as an associated measure. Assessment actions should include provisions by which the environment can be monitored.

Emergency action levels for declaration of a facility or site emergency should be defined in terms of instrument readings or alarms. To avoid unnecessary response to false alarms, the activation criteria for monitors should be defined in such a manner as to require a rapid method for the corroboration of an actual alarm condition.

An example of a situation that might fall into this class is an act, circumstance, or event – for example, a serious failure of an experiment – that results in a major disruption of the core with subsequent fission product release. Protective actions are likely to include evacuation of the plant areas other than control rooms and the emergency control center; for example, the evacuation of construction personnel when additional facilities are under construction on the same site.

General Emergency

Hypothetical accidents that have the potential for serious radiological consequences to public health and safety have been postulated. Although the likelihood of such an event is extremely low, emergency plans should include a general emergency class that provides for early warning of the public. Provision also should be made for modification or expansion of protective actions, based upon conditions prevailing at the time of an accident, to include areas in which projected doses to individuals would be likely to exceed the upper limits of protective action guides.

Emergency action levels and other criteria for declaration of a general emergency should be specified in terms of information readily available in the control room. Such information should include the status of engineered safeguards. The selection of the activation levels should be guided solely by postulated conditions within the plant that would be likely to lead to serious releases of radioactive products into the environment.

Coordination with local authorities is an essential element of the planning for this class to ensure the availability of mechanisms for the early warning of the public.

Table 18-1-2 gives a brief survey of, and subsequent response to, each emergency class.

TABLE 18-1-2.
SUMMARY OF EMERGENCY CLASSES AND RESPONSES.

Classes	Description	Response
Personnel Emergency	Restricted in its scope of involvement and will not escalate to a more serious emergency or affect other facility operations	Administer first-aid, summon additional medical assistance, and perform any required decontamination.
Emergency Alert	Involves situations or occurrences that could create a hazard to personnel of the plant.	Requires a state of readiness by the emergency team and the taking of precautionary steps to prevent an accident and the mitigation of the consequences should it occur.
Reactor Emergency	Involves situations or conditions such as those that require activation of automatic protective systems, or those that can be corrected by on-site staff but could escalate to a more serious emergency, affecting the off-site environment.	Requires immediate implementation of on-site emergency procedures and notification of appropriate off-site agencies as to the status of the plant.
Facility or Site Emergency	Involves accidents in which an uncontrolled release of radioactivity to either water, air, or ground has occurred; and the initial assessment indicates that off-site environments could be affected.	Possible evacuation of some area of the facility or site. Requires immediate notification of appropriate off-site agencies and protective actions to correct the situation.
General Emergency	Existing in-plant situation that resulted in, or could lead to, a serious release of radioactivity, causing personnel exposures or undue risks to the public.	Required actions to correct the situation and coordination with local off-site agencies to ensure the mechanisms for the early warning of the public.

DEVELOPMENT OF THE EMERGENCY PLAN

After the emergency team organization has gathered the necessary data, has identified the potential problem, and evaluated the potential emergencies and hazards, the organization should prepare a written emergency plan. The plan should contain all relevant facts established in the preceding steps. These facts include the following:

- A copy of the inspection checklist utilized in gathering the data.
- Floor plans, sketches, drawings, and other documents.
- A list and description of all hazards.
- A description of each potential emergency and methods of handling each (including the notification and transmittal of information discussed under the next two headings of this module).
- A description of the emergency organization and of the duties of assigned emergency personnel.
- Written documentation for each point within the plan.
- Provisions for plan revision at least annually or as required by changes within the facility.

Accident notifications and transmittal of required information are important parts of the emergency plan.

Accident Notifications

During the first hectic minutes of an emergency, several things are happening simultaneously; some of these events require the attention of an individual who has the ability to function in a calm and efficient manner without being affected by events of the existing emergency. The initial notification of an accident and request for aid from off-site support agencies should be made by a person who has had prior training or instruction concerning what information is to be transmitted and to whom the calls should be placed. It is important to remember that in an emergency situation, for an individual to remember and adhere to more than a few basic and simple rules is almost impossible. To insure that the proper notifications are made, emergency-notification rosters and reporting procedures should be available at telephones and at other communication systems. As a suggestion, these documents should be printed with large, bold-face type on bright-colored paper. The emergency-notification roster should contain the names and telephone numbers of management as well as supervisors of responding groups at the installation and off-site support agencies such as fire departments, hospitals, ambulance services, insurance carriers, and official governmental agencies that require notification. The use of an emergency notification roster similar to the one presented in Table 18-1-3 will be helpful in making requests for assistance and the required notifications in a timely and orderly manner.

TABLE 18-1-3.
EMERGENCY NOTIFICATION ROSTER.

FACILITY PERSONNEL

	Name	Title	Work Phone	Home Phone
1.		Facility Director		
2.		Facility Manager		
3.		Operation Manager		
4.		Safety Officer		

FACILITY GROUPS

	Groups	Emergency Phone	Business Phone
1.	First Aid/Medical		
2.	Radiological Safety Office.		
3.	Police/Facility Security.		
4.	Public Information Office		

OFF-SITE AGENCIES

	Agency	Emergency Phone	Business Phone
1.	Ambulance Service		
2.	Hospital Services		
3.	Fire Department		
4.	State Department of Public Safety		
5.	County Sheriff Department		
6.	City Police Department.		
7.	USNRC Region, ___, Office of Inspection and Enforcement		
8.	Insurance Carriers.		
9.	State Department of Health.		

Transmittal of Required Information

The person making the initial report of an accident or an emergency situation must ensure that all essential information is transmitted in the preliminary notification. The development of a simple notification procedure will greatly aid the individual charged with making these notifications. This procedure should be printed in bold type and posted in strategic locations, preferably adjacent to telephones and the emergency notification roster. A suggested notification procedure is presented in Table 18-1-4.

TABLE 18-1-4.
EMERGENCY NOTIFICATION PROCEDURE.

TRANSMITTAL INFORMATION

This is ______________________ of the ______________________ reporting
(name of the person) (name of the facility)
an emergency. We are located at ______________________. The
(description of location)
location of the emergency is (in detail) ______________________
(building number or name)
____
Location in the building (1st floor, North wing, etc.)

EMERGENCY DESCRIPTION

1. Nature and Severity of Emergency.
   - a. Fire.
   - b. Personal injury.
   - c. Other (radioactive spill, etc.).
2. Radioactive Materials/Radiation Involved.
   - a. Name of radioactive material.
   - b. Form of material (solid, gaseous, liquid).
   - c. Radioactivity (release, airborne, etc.).
   - d. Amount of material (μCi, mCi, Ci).
   - e. Possible effects upon public health and safety.
3. Other Information.
   - a. Other notifications made (Nuclear Regulator Commission, State Health Department, etc.).
   - b. Name and telephone number of public information officer.
   - c. Are news media on the scene or aware of the emergency?
   - d. Emergency team director.

   NOTE: All the suggested information will not be available or required for the initial notification; therefore, subsequent notifications must be made as additional information becomes available.

CASE HISTORIES OF RADIOLOGICAL ACCIDENTS

The control and handling of nuclear accidents is a relatively new field and, as such, is in a continual process of evolution. As in many new fields, experience is an excellent teacher, and much can be learned from review of the accidents that have occurred. By observing accident histories, personnel can avoid mistakes in the handling of subsequent accidents. Improved means of accident control can be implemented. The following accident histories are presented for this purpose.

THE WINDSCALE ACCIDENT, OCTOBER 8-12, 1957

The reactor located at Windscale, England, was one of two air-cooled, graphite moderated, natural uranium reactors utilized for plutonium production. At the time of the accident, experiments that released stored energy from the irradiated graphite by annealing the material were being performed. Normally, this process releases energy at a controlled rate, but on this occasion the energy release was at an excessive rate in parts of the core. The result was a slow and concealed burning process in the core; the process went undetected for a period of four days (October 8-12, 1957) because of insufficient instrumentation. The release of radioactivity finally was detected by an air sampler approximately one-half mile downwind from the reactor stack. The air sample read approximately 300 dpm/m^3, or about ten times the normal background radiation level.

Consequent visual inspection of the core revealed that some of the fuel elements were ruptured and were glowing red.

Since the ruptured fuel elements could not be removed from the reactor to shut it down, the reactor finally was cooled by being flooded with water.

Steps immediately were taken to determine the external dose and the isotope quantities ingested by the population as a result of the release. The findings revealed that the minimum external dose that could have been received by a person remaining in the area of maximum exposure for one week was in the range of 30-50 mR (Figure 18-1-2). Under the circumstances, this amount was considered negligible.

The average air contamination, as determined from 12,000 samples, reached a peak at 4.5×10^{-7} μCi/ml, with an average concentration of 4.5×10^{-9} μCi/ml (Figure 18-1-3). This concentration is 50 percent greater than the International Committee on Radiation Protection standard for continuous exposure to ^{131}I. Tests revealed that the concentrations of ^{89}Sr and ^{90}Sr in milk and food were below maximum permissible levels.

As a result of the accident, the following amounts of activity were estimated to have been released to the atmosphere:

Isotope	Curies
^{131}I	20,000
^{137}Cs	600
^{89}Sr	80
^{90}Sr	9

The sizeable release of ^{131}I presented the greatest hazard to the large dairy industry in the area. A full-scale milk-sampling program immediately was undertaken. Persons who lived as far as 24 miles downwind from the reactor were scanned with a scintillation detector to determine

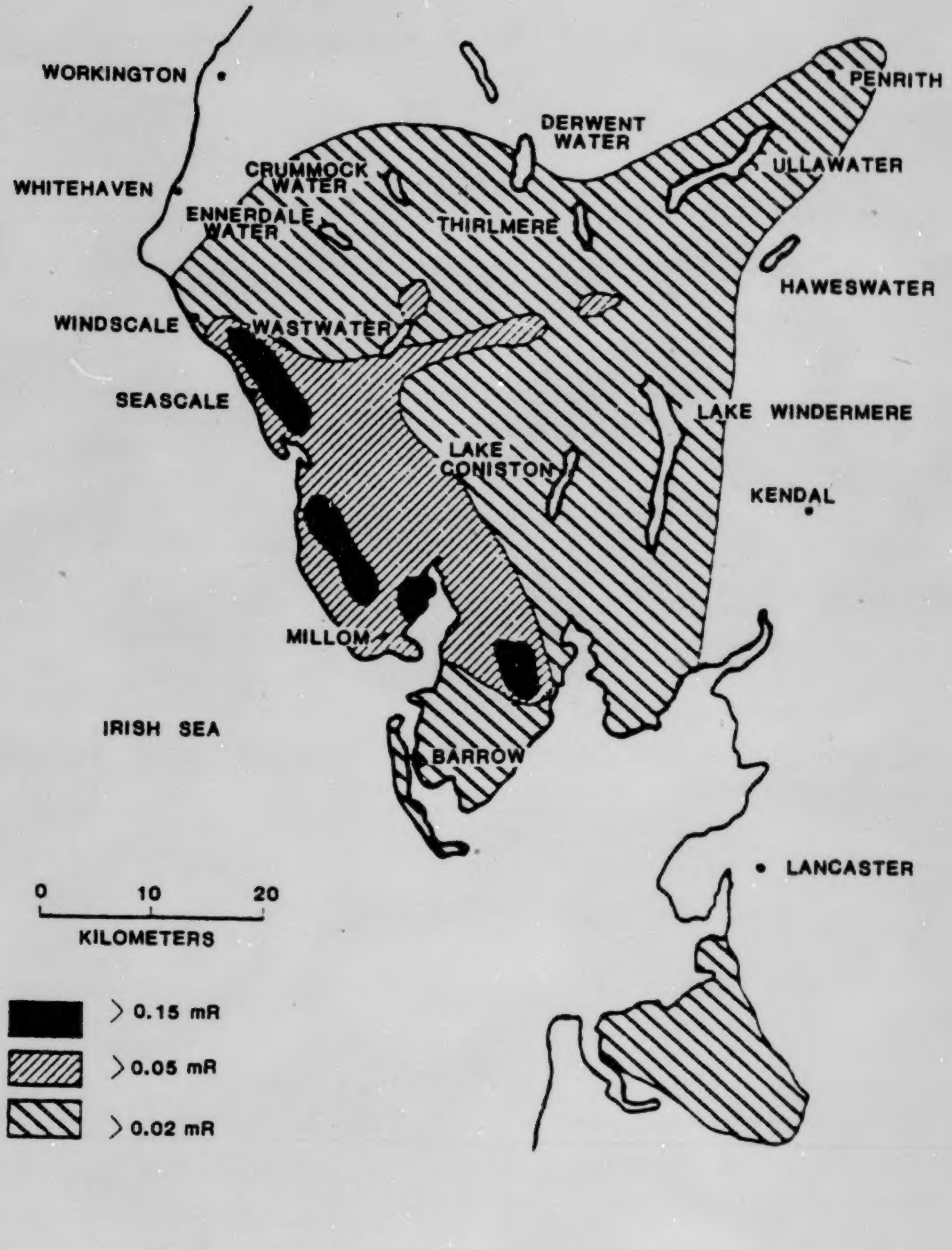

WORKINGTON
PENRITH
DERWENT WATER
CRUMMOCK WATER
ULLAWATER
WHITEHAVEN
ENNERDALE WATER
THIRLMERE
HAWESWATER
WINDSCALE
WASTWATER
SEASCALE
LAKE WINDERMERE
LAKE CONISTON
KENDAL
MILLOM
IRISH SEA
BARROW
LANCASTER
0
10
20
KILOMETERS
> 0.15 mR
> 0.05 mR
> 0.02 mR

Figure 18-1-2. Maximum exposure from the Windscale accident.

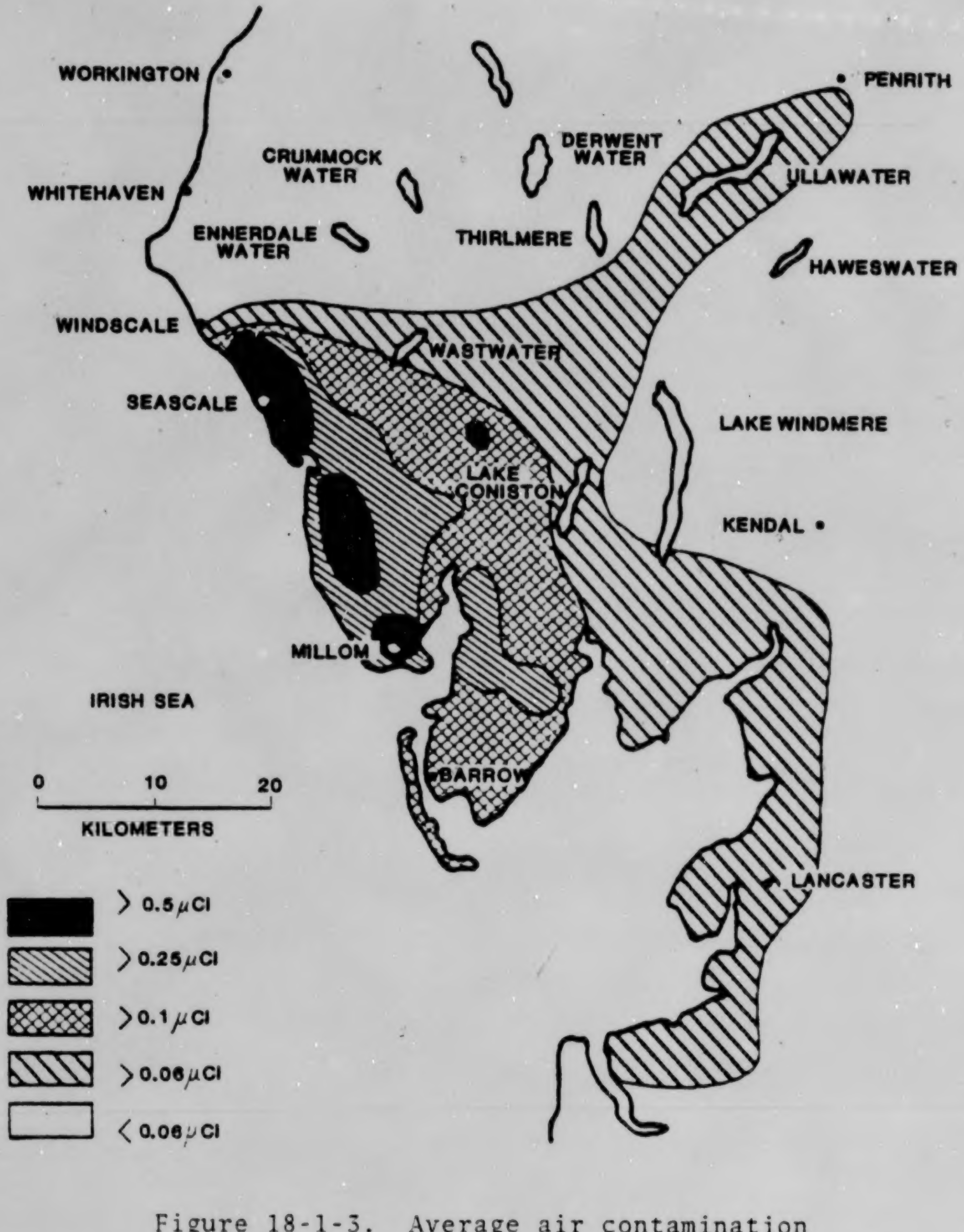

WORKINGTON
PENRITH
CRUMMOCK WATER
DERWENT WATER
WHITEHAVEN
ULLAWATER
ENNERDALE WATER
THIRLMERE
HAWESWATER
WINDSCALE
WASTWATER
SEASCALE
LAKE WINDMERE
LAKE CONISTON
KENDAL
MILLOM
IRISH SEA
BARROW
0
10
20
KILOMETERS
LANCASTER
> 0.5μCi
> 0.25μCi
> 0.1μCi
> 0.06μCi
< 0.06μCi

Figure 18-1-3. Average air contamination from the Windscale accident.

their internal doses of ^{131}I. The highest dose found in children was 16 rad while the highest adult dose was 9.5 rad.

Gamma spectrometric analyses revealed that the amount of ^{131}I in milk exceeded 0.1 μCi/l in an area of 200 square miles southeast of the reactor. The sale of milk from this area was restricted until November 23, 1975.

Many lessons were learned from this incident. By far the most important of these is that very few local health physics organizations are large enough to be capable of handling an accident of this magnitude. During the Windscale incident, resources were pooled from throughout the United Kingdom.

A determination was made that, as far as ^{131}I is concerned, a level of 0.1 μCi/l in milk will result in a thyroid dose of 20 rem or more. An indirect means of estimating the amount of ^{131}I in the milk was developed as a result of the accident. This rule-of-thumb estimate states that the amount of ^{131}I in milk will "exceed 0.1 μCi/l if the milk is produced by cows grazing in an area in which the gamma levels exceed 0.05 mR/hr."

This accident created a tremendous disturbance in the normal activities of approximately 100,000 people and affected a geographical area of between 200 and 300 square miles. One outcome from the accident was the recognition by the authorities that in the emergency state they were confronted with many serious problems that they had not anticipated and that they had no plan of action for coping with a radiological emergency of this magnitude. The accident pointed out several weaknesses that required immediate attention by the entire nuclear community; for example, the need for emergency plans, which included all support and governmental agencies that could assist with the evaluation of the associated hazards and could respond with corrective actions that would minimize the impact of the accident on the community.

THE LOS ALAMOS SCIENTIFIC LABORATORY CRITICALITY ACCIDENT, DECEMBER 30, 1958

This criticality accident occurred during an inventory at a plutonium extraction and purification plant. The plant's primary objective was to recover plutonium residues from machinery. In the ordinary operation of the plant, most of the plutonium was extracted by chemical means, giving concentrations of several grams-per-liter of solvent. Small amounts of the plutonium normally remained behind in the extraction equipment, but periodically were separated and collected. Ordinarily, high-level material was stored and handled separately from that obtained when the tanks were cleaned.

Inadvertently, highly concentrated plutonium was added to a tank that contained low-level material. As a result of this error, the tank contained –

- 87.4 gallons of aqueous solution, with 40 g of Pu.
- 42.2 gallons of solvent (in one layer), with 3.27 kg of Pu.
- Solids containing 60 g of Pu.

The material in the solvent layer, which was immiscible with the water layer, was barely subcritical before the inventory operation started.

Criticality resulted when the chemical operator started a stirrer in the tank. Effectively, the stirrer caused a one-half inch decrease in the radius of the solvent layer, thereby concentrating the plutonium and forming a critical mass. Later analysis demonstrated that the number of fissions that occurred was in the neighborhood of 1.5×10^{17}. Neutron-induced gamma radiation levels in the room following the fissioning were as follows:

Date	Time	Radiation Level
12-30-58	4:40 P.M.	20 R/hr at 25 feet
	9:45 P.M.	0.1 R/hr at 25 feet
1-5-59	9:00 A.M.	2 R/hr at contact

When the solution went critical, there was a blue flash and the operator fell off his stand. The tank was moved 3/8 inch but was not ruptured and no contamination was spread. After the excursion, the operator turned the stirrer off and then on again.

Two other operators who were in the same building went to the man's aid, one of them passing very close to the tank. Suspecting an acid burn, they led the injured man to a shower; and the second operator turned off the stirrer as he passed the tank for the second time.

The highly-exposed operator went into deep shock shortly after exposure, but regained consciousness about six hours later. He died at 3:15 a.m. on January 1, 1959. The radiation dose to the highly-exposed operator was estimated to be 12,000 rem ± 50%. A dose of 134 rem was estimated for the operator who turned off the stirrer and a 53-rem dose was estimated for the operator who assisted with the rescue.

A number of lessons were learned as a result of this incident:

- Reliance upon operational procedures is not always safe; the possibility of human error never must be overlooked.

- Radiation alarm and emergency procedures were inadequate. (Two operators thought that the accident involved an electrical short or chemical explosion, and they did not know that high radiation intensities existed in the room.)
- The design of all atomic processing installations should include consideration of all parameters in the equipment, including criticality safe geometries for process vessels and alarms.

THE OAK RIDGE PLUTONIUM RELEASE, NOVEMBER, 1959

In November, 1959, a chemical explosion occurred in a plant for the chemical processing of highly-irradiated reactor fuel. The explosion evidently was the result of insufficient flushing of an evaporator after decontamination. The acid residues in the tank reacted violently when hot nitric acid was added.

The explosion blew out a door, spreading plutonium contamination to the street and surrounding buildings. Not only was the individual cell in the processing area contaminated, but the plutonium was forced through wiring conduits into the remainder of the building. Airborne contamination outside the building then was pulled into the ventilating system of a nearby reactor. The radioactive contamination was spread over a large area of the reactor facility (Figure 18-1-4).

Activity released in the explosion ran as high as 10^8 dpm/100 cm^2 in the cell involved, to an average of 100 dpm/100 cm^2 in the street. A penthouse above the cell was

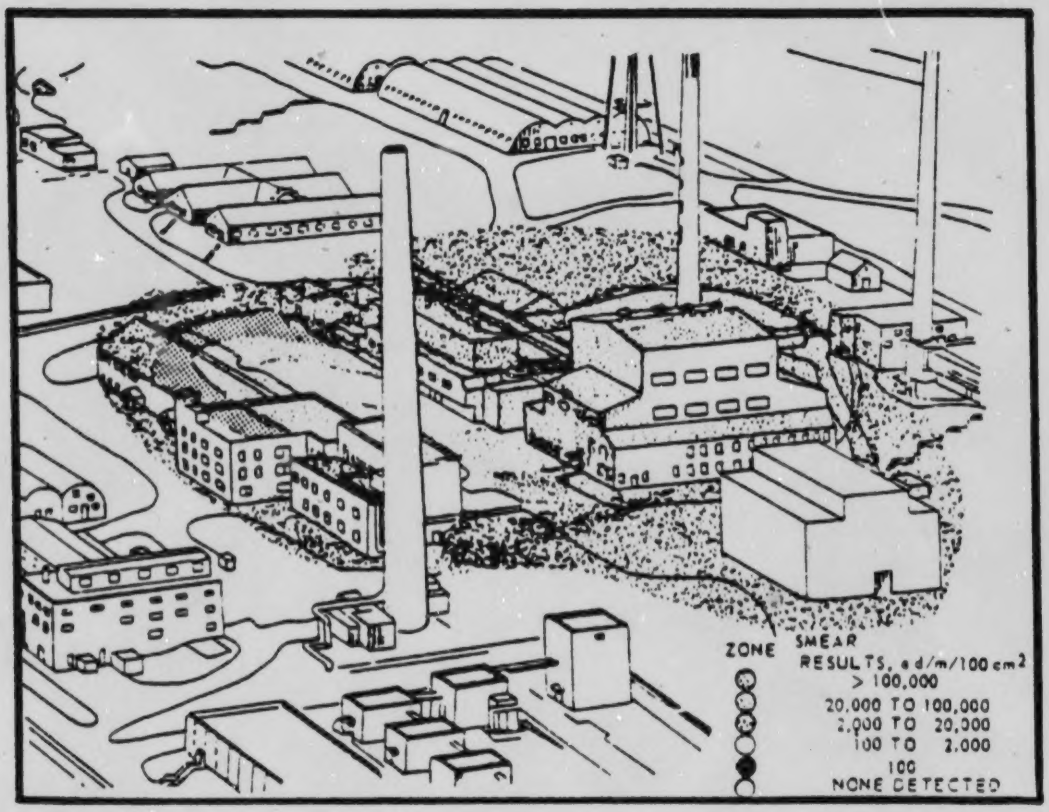

ZONE
SMEAR RESULTS, α d/m/100 cm2
> 100,000
20,000 TO 100,000
2,000 TO 20,000
100 TO 2,000
100
NONE DETECTED

Figure 18-1-4. Oak Ridge plutonium contamination.

contaminated to 50,000 dpm/100 cm^2, and some streets and buildings in the vicinity were contaminated to as high as 100,000 dpm/100 cm^2. Under these conditions, it is a tribute to the accident control personnel that no one received more than the maximum permissible body burden.

A procedure for decontamination was set up, starting at the least highly contaminated areas and moving up to higher levels. Initially, much of the plutonium was fixed in place by the resurfacing of roads and the spray painting of buildings, equipment, and even grass. A number of procedures were employed for the final decontamination, including the use of vacuum cleaners, abrasion techniques, and acids. Over eight months were required for the complete "cleanup" of the area. Significantly, only about 15 grams of plutonium were blown out of the evaporator cell, but this relatively small amount of material resulted in an expense of over $100,000.00 and an eight-month shutdown of an important research facility. The lesson learned from this accident was that only a small amount of radioactive material can cause a severe and costly contamination problem.

THE SL-1 REACTOR INCIDENT, JANUARY 3, 1961

The SL-1 was an experimental boiling-water, low-power nuclear reactor. It had been shut down on December 23, 1960, after approximately two years of operation. Routine maintenance was scheduled, and the SL-1 was to resume operation on January 4, 1961.

On the night of the accident – January 3, 1961 – three military personnel were on duty at the reactor. A security guard at a neighboring area noted that the portal radiation monitor near him had alarmed. No one was present, so he reset the alarm, which again rang. He telephoned the instrument repair section and reported a malfunctioning monitor.

The first indication that anything had gone amiss was the activation of a heat detection alarm, which sounded at the fire station. The fire department and security units reported to SL-1. The assistant fire chief entered the building, read radiation intensities on the order of 25 R/hr, and retreated from the building after searching the lower levels for the three men. Fifteen minutes later two more firemen and a health physicist re-entered the building, read radiation intensities of about 500 R/hr (available instruments read only 500 R/hr full scale and were "pegged"), and evacuated the building. Fifty minutes later, after it had been positively determined that the three operators had not left the area, two more personnel entered the operating level and found two of the operators, one of whom was still alive. They retreated and obtained help. The one operator who was alive was removed, but died shortly thereafter from head injuries. The second body was removed on the evening of January 4. The third man eventually was discovered pinned to the ceiling by a control rod cover. The last body was removed several days after the accident (the morning of January 9).

Radiation levels in the SL-1 building were in the range of 1000 R/hr. The bodies of the operators read 100 to 500 R/hr at six inches. This is the first time that human bodies were, in themselves, hazardous sources — an entirely new phenomenon. High radiation levels made impossible the immediate disassembly of the core to prevent further excursions and to determine the cause of the accident. The core is estimated to have contained one million curies of long-lived fission products. The core and pressure vessel of the reactor were not removed to hot cells for dismantling until eleven months after the accident.

Of the more than 200 people involved in the incident, only 22 received doses in excess of the permissible maximum. The maximum gamma dose was 27 rem, and the maximum whole-body beta dose was 120 rem. The monetary loss from the excursion was $4,350,000.

Although the actual cause of the excursion has not been determined, it probably was the excessive withdrawal of the main control rod while one of the operators was attempting to reconnect it to the drive mechanism.

Several lessons were learned from SL-1 accident, one of which was that although the building was not designed to contain released material, it allowed only a relatively small amount of active material to escape (about 10 Ci ^{131}I); and external environmental contamination was slight. Other lessons learned from this incident demonstrated that very high-level beta-gamma instruments are needed on all emergency teams. Their range should be on the order of 10,000 R/hr.

The possible need for decontamination facilities for a large number of persons, and the need for medical facilities for a large number of contaminated and injured personnel, were brought out as a result of this accident. Also, demonstrated was the need for the protection of team personnel from overexposure in initial efforts to preserve their usefulness in later operations.

THE THREE MILE ISLAND INCIDENT, MARCH 28, 1979

The TMI-2 is a pressurized water reactor (PWR) designated as "Three Mile Island Unit 2" at the Nuclear Power Generating Station located near Middletown, Pennsylvania. On the morning of March 28, 1979, the reactor was operating at 98% full power when a series of events resulted in the loss of the reactor for its purpose of producing electricity, and in the most highly-publicized nuclear accident in the history of the nuclear power-generating industry.

The complex chain of events that led to the accident began at approximately 4:00 a.m. on the morning of March 28, 1979. They began when a condensate pump stopped; and the loss of suction, in turn, tripped the feedwater pumps, resulting in a malfunction of the main feedwater system for the steam generator. The auxiliary feedwater system was to start automatically, but did not because a number of valves in the system had been left closed. With the loss of feedwater, the steam generators ran dry, resulting in the tripping of the turbine generator and in the temperature and pressure of the primary coolant exceeding operating parameters. This overpressurization of the system tripped an alarm which scrammed the reactor.

The loss of feedwater in the steam generator resulted in a sharp rise in the primary loop pressure to some value between 2250 and 2350 psi, which tripped a relief valve at the top of the pressurizer. This valve allowed the primary coolant to be transferred to a quench tank located in the reactor containment building. The pressures in the primary loop dropped to 2200 psi; but unfortunately, the relief valve stuck open, allowing a continuous discharge of coolant from the primary system. The emergency core-cooling system (ECCS) started automatically at approximately two minutes into the accident sequence. The flow of coolant through the open relief valve in the pressurizer continued to fill the quench tank; and approximately fifteen minutes into the accident, a rupture disc in the tank blew open, releasing approximately 10,500 gallons of primary coolant to the floor of the reactor containment building. The released coolant triggered the operation of a sump pump, which transferred the coolant to a holding tank in the auxiliary building that already was partly filled. Again, water was spilled to the floor when tank capacity was exceeded. The radioisotopes of krypton, iodine, and xenon present in the coolant began escaping to the environment through the auxiliary building's ventilation system. The ventilation system's filter stopped (trapped) most of the iodines, but the noble gases of xenon and krypton were released.

This is only a brief summary of the complex sequence of events contributing to this accident. A presentation of all the information would require much more space than is available in this module; however, a review of the population dose and health impact of the accident at the Three Mile Island Nuclear Station is highly recommended. Such a review was compiled by the Ad Hoc Population Dose Assessment Group, which presented data for a preliminary assessment for the period of March 28 through April 7, 1979. This document, entitled Population Dose and Health Impact of the Accident at the Three Mile Island Nuclear Station, is available from the U.S. Government Printing Office, Washington, D.C. 20402, stock number 017-001-00408-1. The Nuclear News "Special Report," dated April 6, 1979, and published by the American Nuclear Society, 555 N. Kensington Avenue, LaGrange Park, Illinois 60525, is suggested for reading for an indepth review of the Three Mile Island accident.

We will continue to learn from each individual accident. A number of radiological accidents have been added; and although these are not all of the accidents that have occurred, they do present an overall view of the broad spectrum of accidents that can occur. One might note that the majority of the accidents have occurred from poor judgment that resulted in human error. One also might observe that the development of emergency plans, which requires the recognition and evaluation of potential emergencies, can make a positive contribution toward accident prevention. Thus, the preparation of emergency plans results in the additional benefit of greatly reducing the frequency, as well as the severity, of radiological accidents.

EXERCISES

1. List the responses to the following emergency classes:
    a. Personnel emergency.
    b. Emergency alert.
    c. Reactor emergency.
    d. Facility or site emergency.
    e. General emergency.
2. Briefly describe what happened in the following radiological accidents:
    a. The Windscale accident.
    b. The Oak Ridge accident of 1959.
    c. The SL-1 Reactor accident of 1961.
    d. The Three Mile Island accident of March 1979. (This accident will be discussed in more detail in the Procedures section of this module.)

MATERIALS

Each student and instructor should have a copy of the following booklets (referred to in the Subject Matter and Reference Materials sections of this module):

Ad Hoc Population Dose Assessment Group. Population Dose and Health Impact of the Accident at the Three Mile Island Nuclear Station. Washington, D.C.: U.S. Government Printing Office, May 10, 1979.

American Nuclear Society. "A Special Report." Nuclear News (April 6, 1979). Order from the following address: 555 N. Kensington Avenue, LaGrange Park, Illinois 60525.

PROCEDURES

DOSE AND HEALTH IMPACT OF THE ACCIDENT AT THREE MILE ISLAND

1. Read the work Population Dose and Health Impact of the Accident at the Three Mile Island Nuclear Station. (This document is referenced in the Subject Matter, Materials, and Reference Materials sections of this module.)
2. The instructor will assign a section or portion of this document to each student, who will discuss the assignment.
3. The instructor will arrange a group discussion on the importance of radiological emergencies.

THE SEQUENCE OF EVENTS DURING THE ACCIDENT AT THREE MILE ISLAND

1. Read "A Special Report," the Nuclear News publication referenced in the Subject Matter, Materials, and Reference Materials sections of this module.
2. Write a paper (whose length will be assigned by the instructor) that summarizes the sequence of events during the accident. Discuss, in particular, how the human errors could have been avoided and how, once the accident was in progress, it could have been brought under control with less impact.
3. The instructor will arrange a group discussion on the subject, "Lessons Learned from the Three Mile Island Accident." Include in the discussion any suggestions of how such mistakes as those made when the valves were left closed can be avoided.

DATA TABLE

None.

48

REFERENCE MATERIALS

Ad Hoc Population Dose Assessment Group. *Population Dose and Health Impact of the Accident at the Three Mile Island Nuclear Station*. Washington, D.C.: U.S. Government Printing Office, May 10, 1979.

American Nuclear Society. "A Special Report." *Nuclear News* (April 6, 1979). Order from the following address: 555 N. Kensington Avenue, LaGrange Park, Illinois 60525.

Bates, Eugene F. *Experiences in the Coordination and Training of Off-site Support Agencies for Emergency Planning*. Proc. Triga Owner's Conference, San Diego, California, 1980.

Moe, H.J.; Lasuk, S.R.; Schumacher, M.C.; and Hunt, H.M. *Radiation Safety Technician Training Course*. ANL-7291, Rev. 1. Prepared for Argonne National Laboratory. Springfield, VA: National Technical Information Services, U.S. Department of Commerce, 1972.

U.S. Atomic Energy Commission, Division of Technical Information. *Radiological Emergency Operations*, TID-24919. Washington, DC.: U.S. Government Printing Office.

United States Nuclear Regulatory Commission. *Rules and Regulations Title 10 Code of Federal Regulations*. Washington, DC: Superintendent of Documents, Government Printing Office, latest issue with updated Supplements.

Wang, Y. *Handbook of Radioactive Nuclides*. Cleveland, OH: The Chemical Rubber Company, 1969.

TEST

1. List and discuss the five steps for the development of emergency plans.

2. Define the following terms:

   a. Personnel emergency.

   b. Emergency alert.

   c. Reactor emergency.

   d. Facility or site emergency.

   e. General emergency.

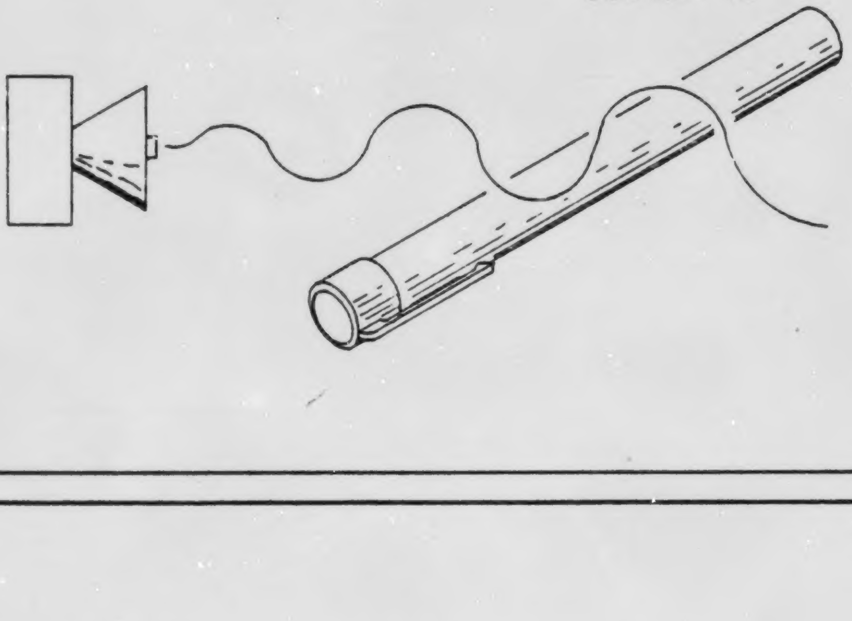
NUCLEAR TECHNOLOGY

MODULE 18-2

EMERGENCY EQUIPMENT FOR NUCLEAR FACILITIES

RADIOLOGICAL
EMERGENCIES

COURSE 18



CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

COURSE 18 RADIOLOGICAL EMERGENCIES

	Module 18-1	General Procedure for Radiological Emergencies
⇨	Module 18-2	Emergency Equipment for Nuclear Facilities
	Module 18-3	Surface Contamination – Decontamination
	Module 18-4	Criticality Control
	Module 18-5	Control of Radiological Hazards
	Module 18-6	Emergency Planning for Nuclear Facilities
	Module 18-7	Emergency Drills for Nuclear Facilities

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INTRODUCTION

The intent of emergency planning and implementation of procedures is to mitigate the consequences of emergencies. Several limiting factors can affect the overall ability of the emergency team to take control of an emergency situation. For example, if a patient stretcher is not readily available, unnecessary delays may occur in the removal of an injured person from the accident area to a more desirable location. Emergency equipment clearly must be of an acceptable type and must be distributed from a control center near any possible emergency.

The emergency equipment discussed in this module includes rescue equipment, protective clothing, respiratory apparatus, personnel monitoring equipment, detection instruments, air monitoring gear, and auxiliary equipment.

MODULE PREREQUISITES

The student should have completed Course 1, "Radiation Physics"; Course 2, "Radiation Protection I"; Course 11, "Radiation Detection and Measurement"; and Module 18-1, "General Procedures for Radiological Emergencies."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Prepare a list of the type of emergency equipment required for a nuclear facility.

2. Demonstrate a working knowledge of the use and applicability of emergency equipment for various accident situations.
3. Demonstrate the use of emergency equipment in determining the presence of radiological hazards and in preventing these hazards from escalating to more serious conditions.

THE CONTROL CENTER

In all emergency situations, some location should be designated as a control center, or base of operation, for emergency action. Preferably, the location of the center should be predetermined and should have emergency equipment stored close at hand. The control center should be close enough to the immediate emergency to oversee operations effectively, but should be far enough away from the actual activity to function efficiently.

One individual should be placed in charge of the control center and, thus, of all emergency operations. Another person should be given the responsibility of recording every detail of what transpires during the emergency, including the data and information coming in from the emergency situation. All communication with outside sources concerning the emergency situation should be through this center. Therefore, the center should be equipped with an Emergency Notification Roster and telephone lines and other communications equipment that will allow two-way radio communication with police, fire departments, and other off-site support agencies. Any information released to news media should be carefully worded and in conformance with the public information policy of the facility.

EMERGENCY RESUCE EQUIPMENT

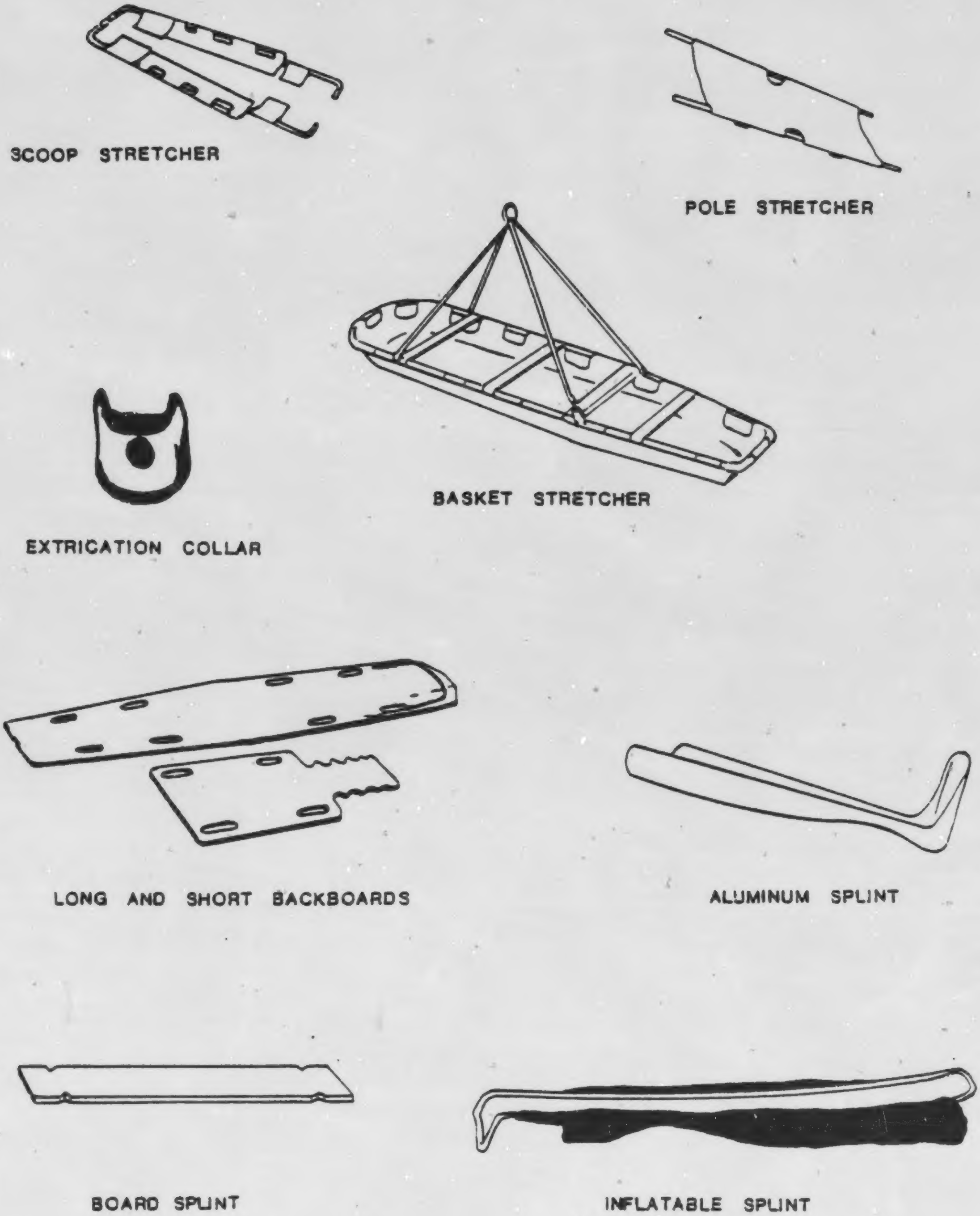
Rescue of injured personnel in emergency situations is much like any other rescue operation, but with special regard given to the radiological aspect. Preservation of life is the first priority. After vital life-saving first aid is administered, the next objective is the protection of the victim from further exposure to radiation. The victim should be moved to a safe area away from radiation hazards as soon as possible. Further life-saving first aid and decontamination take place at this point.

Most equipment for radiological emergency rescues is the same as that for any other rescue operations, although the presence of radiation or radioactive contamination may alter the basic procedure by which it is employed.

- Respirators or breathing apparatus should be used if any airborne contamination or other toxic materials are present. Use of this equipment should be one of the first steps taken. Types and application of different types of respiratory equipment are discussed later in this module.
- Stretchers are required for transportation of the victim. Pole stretchers usually are sufficient, but basket type stretchers, which allow the victim to be strapped in (Figure 18-2-1), may be necessary if the individual is located in an area of difficult access, or must be transported up stairwells. An attempt should be made to prevent the transfer of contamination to the stretcher. Positioning of the stretcher on a temporary clean surface while the victim is being transferred will aid in reducing contamination problems. In general, a grossly contaminated stretcher should not be allowed into the clean zone.
- Blankets are used in rescue attempts involving radioactive materials, not only as an aid in reducing shock and providing warmth, but also

as an aid in removing the victim's contaminated clothing. Figure 18-2-2 illustrates a method for using blankets to accomplish this task. The bottom blanket in the example (and even the top, if necessary) can be replaced by a large plastic sheet.

- Equipment for immobilizing of broken bones may be necessary. A variety of this type equipment is available and should be utilized according to acceptable medical practices and instructions. Contamination of splint devices should be avoided when possible but is secondary to administering the proper medical treatment.
- Radiation detection instruments should be used for locating contamination on victims. This equipment is discussed later in this module.
- Fully equipped first aid kits with the required supply of dressings and bandages should be available for use in any rescue operation.
- Plastic bags are used to hold contaminated clothing and other contaminated objects. Bags used to hold a victim's personal belongings (watches, billfolds, etc.), should be sealed and properly identified. If a victim's hair is contaminated, it should be covered with a plastic bag and sealed with tape.
- All injured persons should be properly tagged for identification before leaving the accident scene for the hospital. The tag should include the victim's name, nature of injuries, and any specific treatment administered, type and amount of radiation and its location, rescuer's initials, and the date and time.



SCOOP STRETCHER

POLE STRETCHER

BASKET STRETCHER

EXTRICATION COLLAR

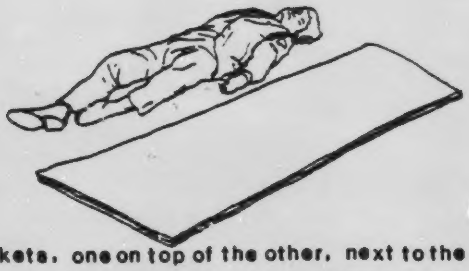
LONG AND SHORT BACKBOARDS

ALUMINUM SPLINT

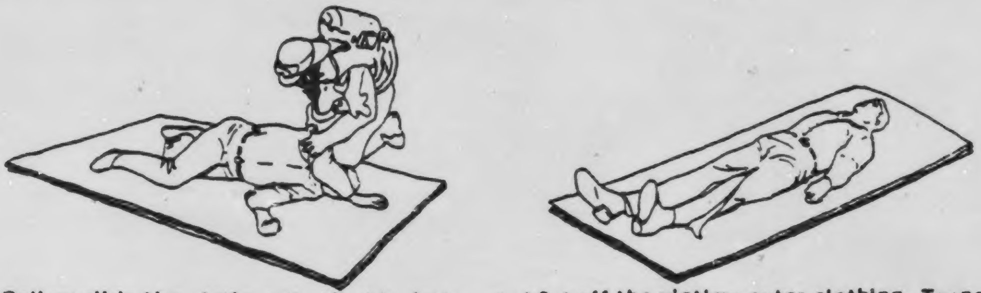
BOARD SPLINT

INFLATABLE SPLINT

Figure 18-2-1. Various stretchers and immobilization equipment.

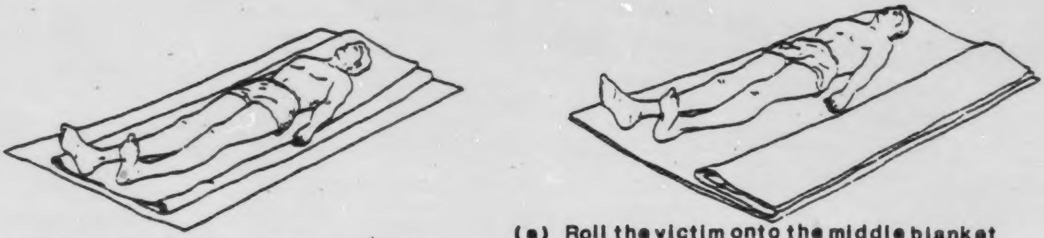


(a) Lay three blankets, one on top of the other, next to the victim.
(The blanket next to the ground immediately becomes contaminated.)



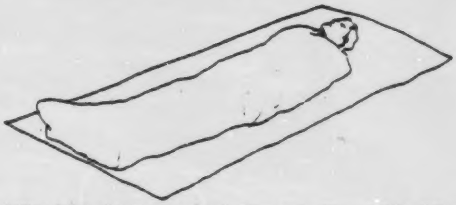
(b) Roll or slide the victim onto the blankets.

(c) Cut off the victims outer clothing. Try not to let any of the outer surface of the clothing touch the skin.



(d) Fold the top blanket under the victim keeping the victim's clothing inside the blanket.

(e) Roll the victim onto the middle blanket.



(f) Wrap the middle blanket around the victim; the blanket and victim are now ready to be moved onto a stretcher.

Figure 18-2-2. Use of blankets in the removal of a victim's contaminated clothing.

Victims in radiological emergencies should be decontaminated as much as possible at the scene. Hopefully, most of the contamination will be removed with the clothing. Skin contamination may be removed with the aid of a cloth or adhesive tape. Areas that cannot be decontaminated immediately should be outlined and covered with dressings, plastic bags, or tape to protect doctors and nurses from becoming contaminated. No attempt should be made to decontaminate wounds; they should be covered with clean dressings. Hospitals receiving victims should be alerted to the fact that the victims may be contaminated.

PROTECTIVE CLOTHING

Personnel working in a situation that involves radioactive contamination should wear proper anti-contamination clothing to prevent their coming in direct contact with radioactive material and to keep contamination from being spread to other areas. The choice of a particular type of anti-contamination clothing is dictated, in part, by the environment in which it is to be worn (such as the amount of contamination present, weather conditions, presence or absence of airborne contamination, etc.). Following are descriptions of common anti-contamination apparel and their use. (Refer to Figure 18-2-3.)

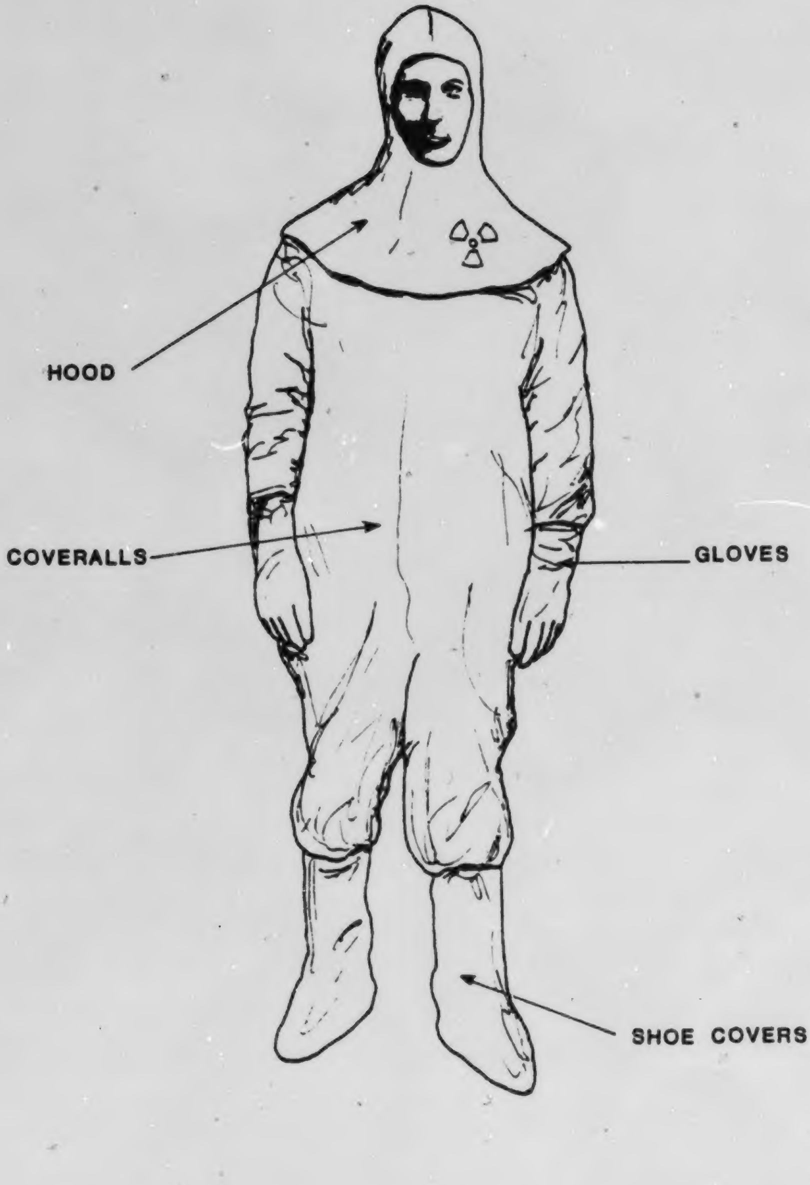

HOOD
COVERALLS
GLOVES
SHOE COVERS

Figure 18-2-3. Some common anti-contamination apparel.

COVERALLS

There are many different varieties of anti-contamination coveralls. Some are disposable; others are made to be laundered. They are available in one or two pieces and can have button, zipper, or drawstring openings. Coveralls are made of cotton, polyester, or plastic, and can be made acid resistant or fire retardant. Clearly, if the coveralls must protect from radioactive contamination in a wet environment or must protect the wearer from the presence of hazardous chemicals such as ammonia or hydrocyanic acid, these factors must be considered in choosing the proper type clothing.

In a dry environment with relatively high levels of contamination, single-piece, closely woven cotton twill coveralls have been used effectively to prevent most contamination from reaching the body. After the coveralls are put on, all openings, slits, or tears are sealed with masking tape. Usually, in highly contaminated areas, a second pair of coveralls is worn over the first and is secured with tape in a similar manner. In addition to decreasing the chance of contamination reaching the body, the second pair of coveralls allows for removal of the highly contaminated outer layer before moving on to an area in which lower levels of radioactive contamination are present.

SHOE COVERS

Shoe covers are worn to prevent the contamination of footwear while working in a contaminated area. However, shoe covers often are unable to hold up under heavy wear, particularly on rough ground, and shoes often become contaminated anyway. Because decontamination of footwear is extremely difficult and often ineffective, it is recommended that expendable shoes be worn into contaminated areas.

Shoe covers are constructed from a variety of materials, of which the more common are canvas, PVC, and rubber. Foot protection in areas of low-level contamination often consists of a pair of canvas shoe covers with elasticized ankles. Canvas covers with vinyl-coated bottoms or plastic shoe covers are a minimum requirement for entrance into areas in which radioactive liquids are present in the contamination. For larger contamination problems, shoe covers that extend up the calf are available in order that the coverall cuff can be tucked in and the juncture sealed with tape. High-topped rubber shoe covers (boots) are recommended for most decontamination situations because of their waterproof quality and ruggedness.

HEAD COVERS

To reduce contamination to the head and scalp, some type of protective covering must be worn. In areas of low contamination, surgical caps often prove adequate, but the type that can be pulled down over the back of the neck is more suitable and is recommended. If the area is grossly contaminated, a plastic or cloth hood that surrounds the face and covers the shoulders and upper chest and back should be worn. Transparent hoods that completely enclose the face and that are equipped with an air supply are available for extreme cases or if airborne radioactivity is present. Air-supplied hoods should be secured along the lower edges with masking tape, leaving only a small opening for exhaust of incoming air supply.

GLOVES

The type of glove protection chosen depends upon the nature of the work to be performed. Surgical gloves allow the sensitivity necessary to perform very delicate work. They also can be worn underneath more rugged gloves as an additional barrier to contamination. Jobs that involve manual labor call for work gloves of cloth, leather, or plastic. Personnel who work in wet conditions or who handle corrosive or caustic materials must wear rubber gloves that extend above the wrist.

Gloves should be worn with the sleeves of the coveralls tucked inside them and should be sealed with making tape. If two pairs of gloves are worn, the outer pair should be worn outside the coverall cuffs and sealed with tape.

PLASTIC SUITS

Plastic suits completely surround an individual and, thus, afford excellent protection in almost any contaminated environment. There are two major types of plastic suits: The first requires an external souce of supplied air and some supplementary equipment, making it difficult to adapt to field operations. The second type of plastic suit can be worn with respiratory devices or a self-contained breathing apparatus. Although it is impermeable to water and gaseous toxic agents, it is more uncomfortable. Both types of plastic suits have the disadvantages of being cumbersome and easily torn.

RESPIRATORY PROTECTION

Respiratory protective devices are tested and approved by the U.S. Bureau of Mines (USBM) and the Department of the Interior for hazards that range from the lack of sufficient oxygen to the presence of toxic gases, radioactivity, or "nuisance" dusts. Specific types of respiratory equipment are designed to "meet the requirements" of a particular hazard. Because of the increased danger of radioactivity (or other toxic materials) when they enter the body, care in choosing the proper respiratory equipment cannot be overemphasized: An error in the proper choice of protective coveralls may result in wasted time or inconvenience, but an error in choice of respiratory equipment could result in the loss of life. (Refer to Figure 18-2-4.)

In practice, the use of appropriate respiratory protection is recommended for anyone who enters an area in which airborne radioactivity is suspected. Use of the equipment is continued until it is established, not only that airborne contamination does not exist, but also that further work will not generate airborne contamination.

Several factors must be considered before respiratory equipment is chosen. Selection and use of the proper devices should be based on the following procedure:

- Identify substance(s) against which protection is required.
- Know hazards and properties of each substance.

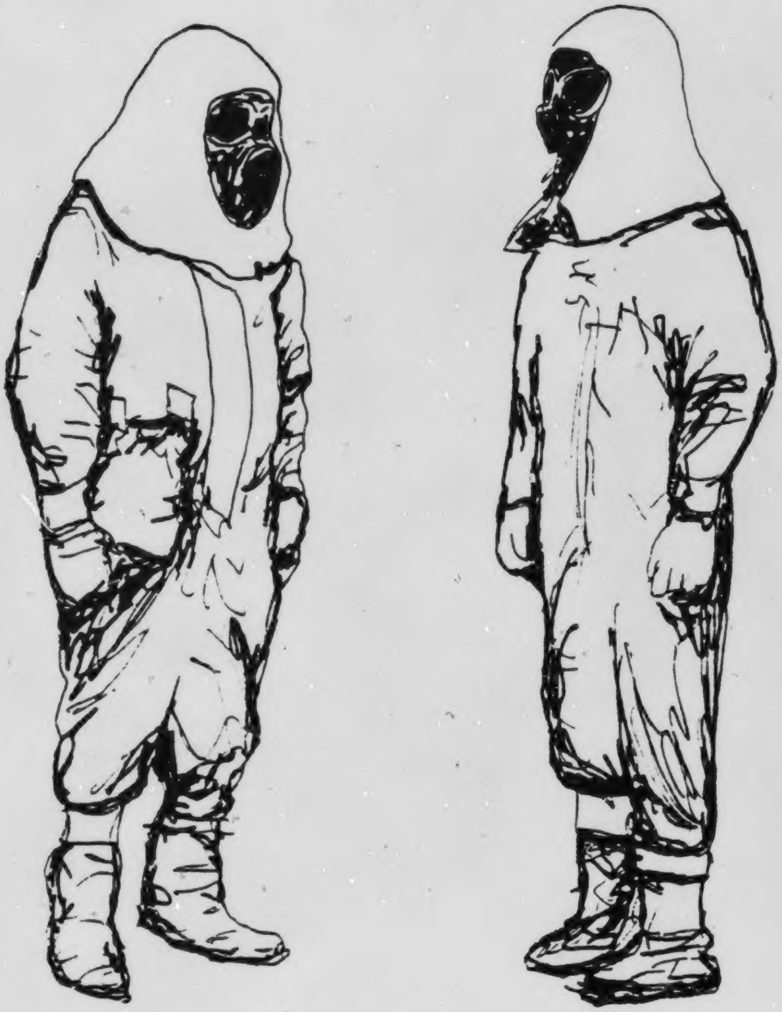


Figure 18-2-4. Emergency team personnel wearing taped anti-contamination clothing and full-face mask (left) and self-contained breathing apparatus (right).

- Determine conditions of exposure and the level of air contamination present.
- Determine whether or not any human capabilities and equipment limitations are essential to the

safe use of specific respiratory equipment.

- Fit respirators carefully, and instruct workers in their use.

There are three major classes of respiratory protective devices:

- Air purifying.
- Air supplied.
- Self-contained breathing apparatus.

One hazard that is applicable to all these types of respiratory apparatus is the presence of petroleum vapors in the airborne contaminants. In this type of environment, equipment cannot be used for prolonged or successive periods without the vapors permeating the rubber parts of the apparatus. Damage can occur to some equipment in as little time as 10-15 minutes.

AIR PURIFIERS

Air purifying devices function by removing contaminants from the atmosphere but are not applicable in areas of oxygen deficiency. Such devices include mechanical filter respirators, chemical cartridge respirators, and gas masks. The air passes through cartridges that retain whatever material they were designed to remove. Service life of cartridges usually is less than 30 minutes and is determined by the following:

- Design: quality of filtering material, amount of fill, packing uniformity, and density.
- Exposure conditions: concentration of impurity, breathing rate, temperature, and humidity.

Air filtering equipment should never be considered adequate protection if the cartridge is not designed for the type contaminant involved or if the concentration of the contaminant exceeds the limits specified on the cartridge.

Mechanical Filter Respirators

These devices are equipped with cartridges that contain some fibrous material that physically traps particulate matter such as dusts, mists, and metal fumes. As a general rule, this type of equipment should not be used for concentrations in excess of 100 times the MPC limit of the contaminant involved.

Chemical Cartridge Respirators

These respirators utilize cartridges that contain various chemicals for the elimination of impurities in the inhaled air. Specific chemicals in the cartridges filter out specific contaminants and should not be used to protect against other contaminants. Cartridges for this type respirator usually are equipped with some type of color code that indicates when the cartridge life has been expended. Chemical cartridge respirators (Figure 18-2-5) should not be chosen for protection against gaseous materials that are extremely toxic in small concentrations, or in any harmful gaseous matter that cannot be detected by odor: If a leak were to develop in the presence of an odorless gas, it could go unnoticed until too late. A mechanical filter often is used in conjunction with a chemical cartridge to afford protection against both particulate and gaseous contaminants.

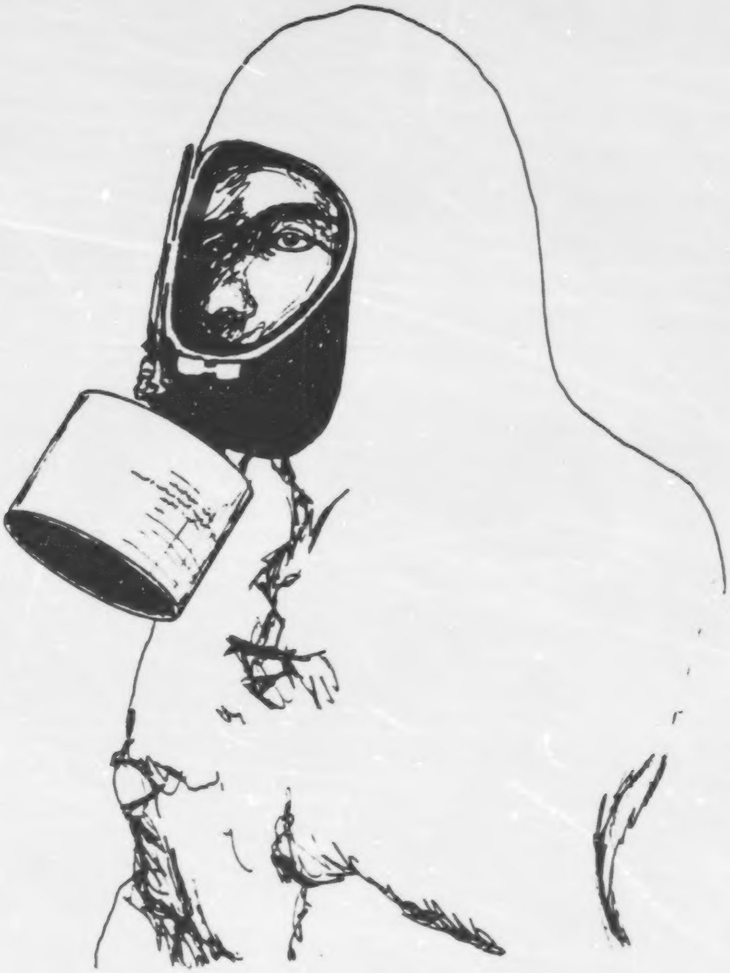


Figure 18-2-5. Cartridge respirator worn with hood.

Gas Masks

Gas masks are designed to be worn in atmospheres that generally contain no more than two percent concentration of toxic gases and vapors by volume. They utilize cartridges similar to those of the above group and work in the same manner.

Before an air purifying respirator is used, the mask and canister should be inspected for physical damage. The individual wearing the equipment should ensure that an appropriate filter or cartridge is being worn. If a chemical cartridge already has been used, do not reuse unless an accurate record has been kept. Attach the cartridge to the face mask, and check air intakes and outlets to ensure that they function properly. Antifog the mask eyepieces and allow to dry. Put on the mask. If it is secured by flexible straps, tighten them from top to bottom. Test the mask for leaks.

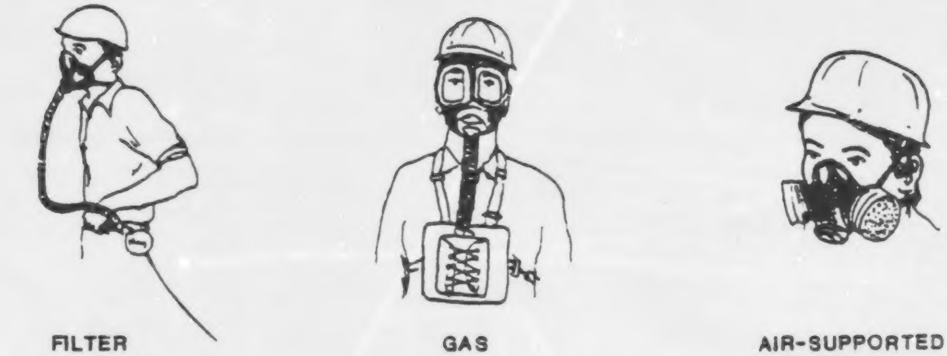
Testing for an air tight seal may be accomplished by tracing the edges of the mask with a smoke tube or pungent odor-producing device. If smoke or odor devices are unavailable, the fit should be checked by covering the air inlet and attempting to breathe in: This should produce a vacuum, and the mask should be drawn toward the face. Checking for leaks is extremely important, as the filtering efficiency is lost if inhaled air passes through any openings other than the filter.

The wearer should be careful to allow himself enough time to leave the contaminated area before the canister life is expended. If high breathing resistance develops or if any leaks are detected by smell, taste, or irritation of the eyes, nose, or throat, the worker should exit the area and obtain new equipment. The worker should exit the contaminated area immediately at the first hint of nausea or dizziness. Also, particular attention should be given to the temperature of inhaled air. A properly operating canister will become warm on exposure to certain gases or vapors, but extremely hot air indicates that concentrations above the canister limit have been encountered. If this occurs, an exit should be made immediately.

AIR-SUPPLIED RESPIRATORS

Air-supplied respiratory devices are equipped with an outside source of air connected to the wearer's face mask by a supply hose, which allows the wearer to stay in an area for an unlimited time. Workers should be careful to place the air source in an area free of contaminants or toxic agents but with an ample supply of oxygen. Various types of respiratory equipment are depicted in Figure 18-2-6.

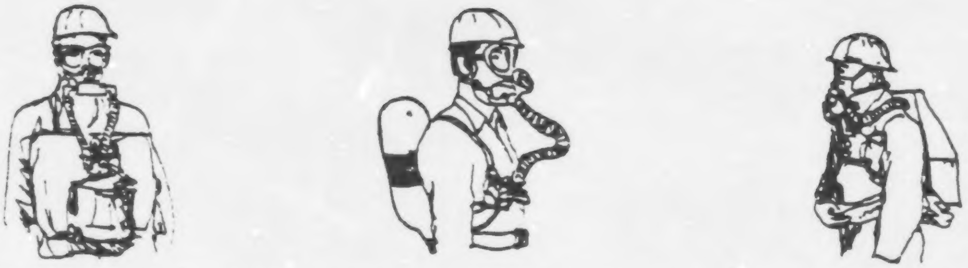
The most frequently recommended type of air-supplied respirator is the postive-pressure type that maintains a positive pressure relative to outside air inside the mask at all times. If a leak occurs in this type of equipment, contaminated air will be prevented from entering the mask. In demand type respirators, air is delivered to the mask only when the wearer inhales. These masks, if coupled with impermeable plastic or rubber anti-contamination suits, provide excellent protection in almost any contaminated atmosphere.



FILTER RESPIRATOR

GAS MASK

AIR-SUPPORTED RESPIRATOR



COMPRESSED OXYGEN CYLINDER REBREATHING APPARATUS

COMPRESSED OXYGEN CYLINDER NON-REBREATHING APPARATUS

OXYGEN-GENERATING REBREATHING APPARATUS

SELF-CONTAINED BREATHING APPARATUS

Figure 18-2-6. Various types of respiratory equipment.

There are, however, some limitations to the use of this type of equipment. It does tend to be bulky, especially when used in conjunction with a plastic suit. Use is restricted to a fixed distance from the air source, based on the allowable hose length, which normally does not exceed 150 feet. The wearer must drag this hose with him wherever he goes. Dragging leads to more complications if radioactive contamination and/or debris are present.

Air-supplied respirators should not be worn in atmospheres immediately harmful to life unless the wearer can escape to fresh air without the use of the respirator: If the air supply fails, the worker could not breathe adequately through the small-diameter air line long enough to ensure escape from the hazardous area. An exception to this rule is a hose mask equipped with a blower. With this device, air is supplied by a blower through a hose having a large inner diameter of approximately 1 inch. If the blower unit fails, the wearer can breathe through this hose long enough to return to safety.

SELF-CONTAINED BREATHING APPARATUS

Because no outside air is allowed to enter the system, this equipment is independent of the surrounding atmosphere and is capable of providing complete respiratory protection in toxic gases and areas deficient in oxygen. This equipment is completely portable, although its size and weight can make it rather cumbersome, particularly if used in an atmosphere requiring the use of a plastic suit. All types of oxygen breathing apparatus approved by the U.S. Bureau of Mines is described in the Bureau of Mines Handbook, which includes information on those units manufactured in the United States. This handbook is suggested as an outside source of required reading.

The three main classes of this type of equipment are oxygen cylinder rebreathing, self-generating, and demand.

Oxygen Cylinder Rebreathing Apparatus

This equipment contains relatively small compressed-air cylinders, which provide oxygen of high purity to the wearer through reducing and regulating valves. The wearer exhales into a container that holds a chemical that removes carbon dioxide from the exhaled breath. The purified air then is mixed with the air from the cylinder.

Self-Generating Oxygen Equipment

This breathing device is similar to the rebreathing type but does not have the high-pressure cylinders or mechanical components. The breather exhales into a canister that contains potassium superoxide, which evolves oxygen when it comes in contact with the moisture and carbon dioxide in exhaled breath. The canister retains the moisture as well as the carbon dioxide, thus reducing the occurrence of lens fogging. This type of equipment is approved by the U.S. Bureau of Mines for use of up to one hour.

The Demand Apparatus

The demand apparatus consists of a high-pressure air cylinder, a demand regulator, a face piece and a tube assembly with exhalation valves, and a method of mounting on the body. The airflow is on inhalation demand, automatically regulating itself to the desired level to compensate for breathing needs. As in air-supplied systems, positive pressure demand apparatus is available where it is unacceptable to allow back leak into the system.

Some types of breathing apparatus can provide a source of air for up to two hours. They are uncomfortable and heavy, weighing up to 40 pounds, and require a minimum amount of formal training and periodic refresher courses for use. The two-hour stay time allowed by this equipment may be necessary for some operations during an emergency situation, and all members of the emergency team should receive formal training in the use and operation of this equipment.

The wide diversity of equipment and operating instructions prohibits inclusion of any specific procedures for equipment operation in this module. However, the majority of these respirators are fairly easy to assemble and to use when one is familiar with them. All workers who may be required to use emergency respiratory equipment should familiarize themselves with the type of equipment that would be employed at their facility.

A brief summary of respiratory hazards and the required protective respiratory equipment is presented in Table 18-2-1.

TABLE 18-2-1. RESPIRATORY HAZARDS AND REQUIRED RESPIRATORY EQUIPMENT.

HAZARD	DEGREE OF TOXICITY	RESPIRATORY PROTECTIVE DEVICE
Oxygen Deficiency	All	Self-contained breathing apparatus Hose mask with blower
Gaseous Contaminant	Immediately dangerous to life	Self-contained breathing apparatus Hose mask with blower Gas mask
	Not immediately dangeous to life	Air-supplied respirator Chemical cartridge respirator
Particulate Contaminant	All	Mechanical filter respirator Air-supplied respirator
Gaseous and Particulate	Immediately dangerous to life	Self-contained breathing apparatus Hose mask with blower Gas mask with special filter
	Not immediately dangerous to life	Air-supplied respirator Chemical cartridge respirator with special filter

PERSONNEL MONITORING EQUIPMENT

In radiological emergencies, dosimeters are used both to measure the exposure an individual has received and as an aid in prevention of excessive whole-body exposure. The dosimetry methods used depend upon equipment available in emergency kits and the type of radiation encountered. Different types of dosimeters and their applications are discussed below.

FILM BADGES

The film badge packet (Figure 18-2-7) is used to measure external radiation exposure. In addition to its use

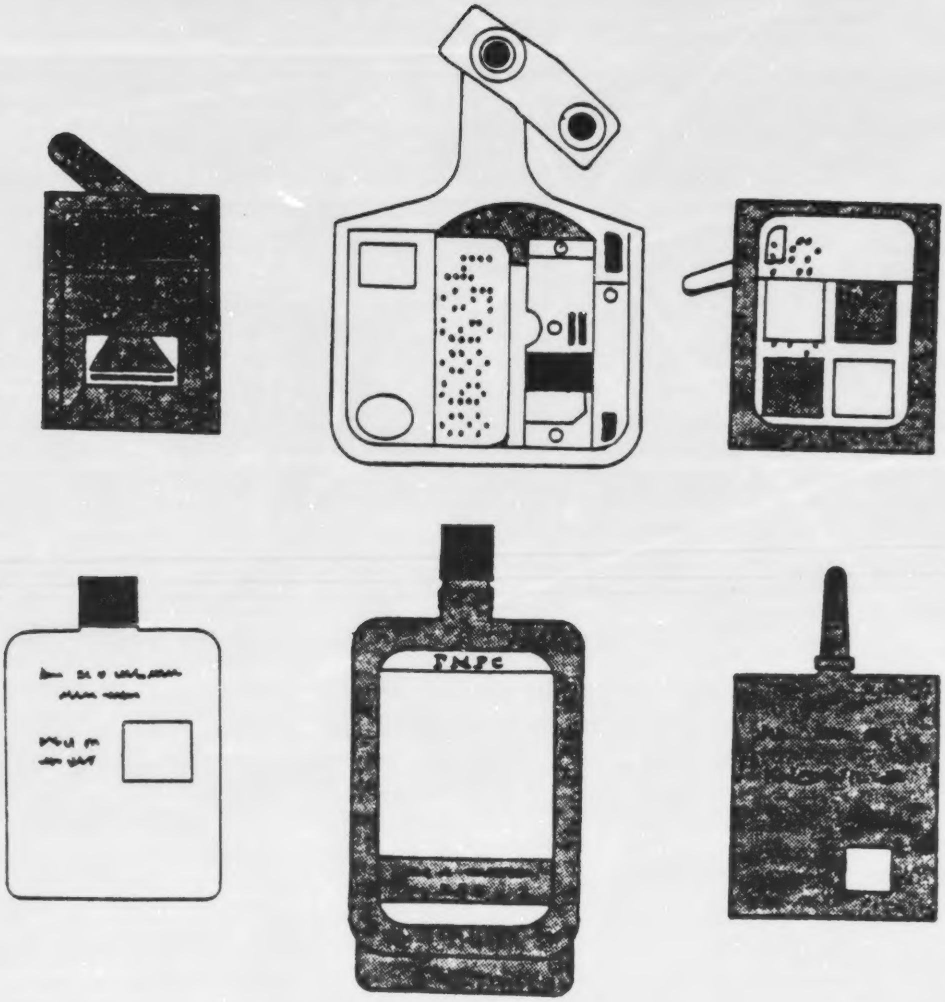


Figure 18-2-7. Various film badges.

as a measuring device, the film badge is also valuable as a permanent legal record of the exposure and, thus, should be worn by all workers in a radiation field. Film badges can be utilized to measure gamma, beta, and fast or thermal neutron exposure, depending upon the type of filters and the film emulsion.

CRITICALITY DOSIMETERS

For areas where there is a possibility of a criticality accident, methods must be provided for measurement of the very large radiation doses that would occur. Materials that have a high probability for capturing neutrons at different energies are used to measure the dose and to provide information about the neutron energy spectrum present during the accident. This type of dosimeter either can be worn or placed in possible criticality areas. Response of certain elements in the body or in metallic buttons, rings, watches, or pocket change can yield this information. Other criticality dosimeters are based upon the fission principle and contain fissile materials. These devices should not be worn by personnel.

High-range gamma exposure dosimetry devices should be provided to personnel in criticality areas, since exposure may be beyond the limits measured by gamma film badges. Thermoluminescent dosimeters can be used for this purpose.

THERMOLUMINESCENT DOSIMETERS (TLD)

Thermoluminescent dosimetry is based upon the phenomenon that when certain types of radiation pass through special crystals, some energy is trapped. Subsequent heating of these crystals to a high enough temperature releases light, which, when measured, is proportional to the amount of radiation incident upon the crystal.

TLDs can be used for detection of gamma, beta, and thermal neutrons. They are much less sensitive to environmental heat, light damage, and moisture than film dosimeters and can measure exposure into the kiloroentgen range. However, measurement of the light emission erases the stored energy, so they do not retain a permanent record.

SELF-READING POCKET DOSIMETERS

Self-reading pocket dosimeters provide an immediate indication of the dose received by exposed emergency-team personnel. The dosimeter consists of a small air-filled chamber around a quartz-fiber electrometer, a small microscope, and a graduated scale across which the shadow of the electrometer moves to indicate dose. These devices are available in ranges of gamma exposures from 0-200 mR to 0-1000 R. It is standard procedure to wear two dosimeters of different range at the same time. They should be worn on the upper front part of the body (such as in a shirt pocket) with little or no shielding between the dosimeter and radiation source.

Self-reading pocket dosimeters are used in conjunction with a dosimeter charger. This battery-operated device allows the dosimeter to be read and provides a method of resetting the hairline on zero. (Refer to Figure 18-2-8.)

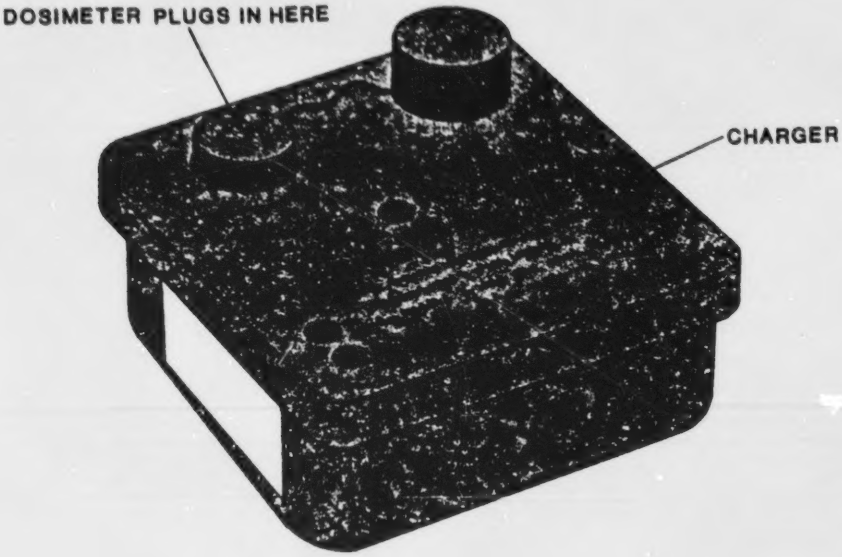


Figure 18-2-8. Self-reading pocket dosimeter charger.

RADIATION DETECTION INSTRUMENTS

Radiation monitoring in emergency situations includes detection of radiation sources and measurement and recording of radiation levels. For use in contaminated areas, detection instruments, with the exception of alpha probes, should be enclosed in plastic bags to prevent their contamination. The choice of a particular type of detection instrument depends upon a number of factors. Some considerations include portability, mechanical ruggedness, ease of use, ease of servicing, ease of decontamination, and reliability. Other factors must also be considered:

- Survey instruments must have the ability to respond to the type radiation being measured. For example, if a beta or alpha radiation field is surveyed with an instrument that detects only gamma radiation, the instrument would indicate safe conditions when, in fact, there may be severe contamination.
- The instrument must have sufficient sensitivity to measure radiation at the desired level.
- The instrument must have an appropriate response time. If the meter responds too slowly, a small area of contamination may not be detected when the probe is passed rapidly over it. On the other hand, too fast a response time may decrease the sensitivity or result in rapid fluctuations of the meter reading.
- Most radiation measuring instruments have a limited energy range in which the radiation dose can be measured accurately.

ALPHA SURVEY INSTRUMENTS

In spite of the fact that alpha radiation is easily blocked by the outer layer of skin, alpha particles can be extremly dangerous if ingested. Alpha radiation can be detected by several types of instruments, including ion chambers, proportional counters, scintillation crystals, and solid-state detectors. Because of the limited range of alpha particles, the alpha detector probe cannot be enclosed in a plastic bag because the bag would prevent the particles from reaching the probe. (Operation and maintenance of the Model PAC-4G Gas Proportional Alpha Counter are discussed in Module 18-3.)

Alpha detectors often are sensitive to beta, or even gamma, radiation. In this case, the discriminator can be used to block out unwanted response, although some low-energy alpha may be blocked out, as well. Another solution is to measure unwanted radiation by blocking alphas with a piece of paper and then subtracting the reading from the overall response. Note: If the covered alpha probe is moved away from the radiation source and if a constant reading is maintained, the probe face is contaminated and should be replaced or carefully cleaned.

Care should be taken not to puncture the delicate detector window: If the window is punctured and a replacement is unavailable, it can be mended in most cases with cellophane tape (which shields alphas, thus decreasing detector sensitivity). Scintillation counters, however, are sensitive to light leaks and must be mended with black plastic tape. Light leaks too small to be seen can be detected and located if various parts of the window are shaded and if the corresponding meter changes are observed.

BETA AND GAMMA DETECTORS

Instruments commonly used for beta and gamma detection are GM detectors, ion chambers, and scintillators. These instruments should be covered with plastic bags when carried into contaminated areas. If the bag covering the detector probe becomes contaminated, it should be replaced. (Operation and maintenance of the Model E-120 Geiger Counter are discussed in Module 18-3.)

Most beta and gamma detectors are equipped with a probe that can be shielded to differentiate between gamma and gamma-plus-beta radiations. The gamma-only reading is subtracted from the beta-plus-gamma reading to find the value of the beta (including "soft" gamma) reading. Usually, these instruments will be calibrated to the gamma radiation; therefore, the beta portion of the readings must be corrected to predict actual dose rate.

NEUTRON DETECTION INSTRUMENTS

Neutrons are not directly ionizing, which makes their detection more difficult. Neutron detectors usually are more bulky and complicated than beta and gamma instruments (Figure 18-2-9). The method of detection may vary according to the energy of the neutron to be detected. Many different neutron-detection instruments have been designed and developed; some of them are listed below:

- Boron chambers are the most common neutron detectors. They can be made to detect slow or fast neutrons.
- Fission chambers are based upon the fission principle. Chambers lined with ^{235}U are used to detect slow neutrons. A lining of ^{238}U is employed in detection of fast neutrons.
- Scintillation detectors are used for either slow or fast neutrons, depending upon the type of crystal inside.

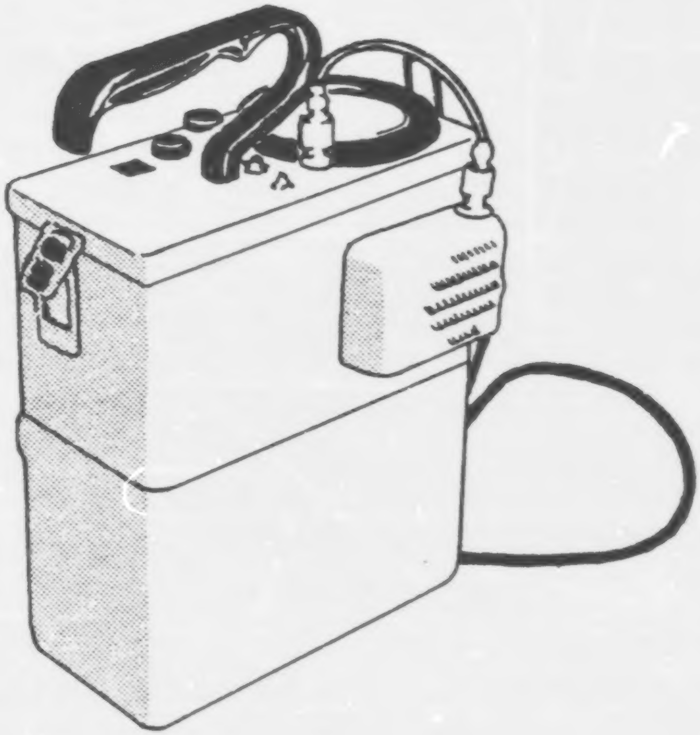


Figure 18-2-9. BF_3 tube type detector (PNC-1) for fast and thermal neutrons.

The overall sensitivity of a thermal neutron detector can be increased if the probe is surrounded with a moderating material that will thermalize some of the fast neutrons and allow them to be detected also. To measure fast neutrons alone with such a detector, the moderator can be surrounded by cadmium, which captures thermal neutrons and allows only fast neutrons to pass through. In the moderator, the fast neutrons are thermalized, and then can be detected.

INSTRUMENT MAINTENANCE

Instruments for use in radiological emergencies should be kept clean and in working order. Following is a general list of minimum action that should be taken in the care of instruments. More detailed requirements depend upon the specific instrument.

- Clean dust and dirt from outside the instrument case, and inspect for external damage.
- Visually check internal electronics for broken leads and dirty connections.
- Examine batteries; replace if necessary. Insure that contacts are good.
- Without changing scale calibration potentiometers, tighten any loose screws.
- Check switches; clean and repair if needed.
- Check instrument with a standard source.

THE MONITORING OF AIR

Air sampling is an extremely important part of a survey in which there is a possibility of significant amospheric contamination. Upon arrival at the radiation incident, one may be faced with almost anything: radioactive noble gases, radioactive water droplets from steam condensation, and/or gross quantities of airborne radioactive particulates, complicated by high winds or operating ventilation systems. Proper placement of air samplers upon this initial arrival at the scene and the proper recording of information obtained are important factors in the assessment of the airborne radiation hazard.

To obtain a background reading, an air sampler should be placed approximately 500 meters upwind of the accident scene for about 30 minutes. Continuous air monitors should be placed at the Hot Line and at about 25 meters downwind from the accident and should be monitored periodically during team operations. (The "Hot Line," as discussed in Module 18-3, is set up adjacent to the contaminated area for the purpose of controlling the spread of radioactive contamination.) The monitors should also be placed in nearby populated areas (particularly downwind) and should be operated until there is no more danger of airborne contamination at that point.

An air-sampling system is basically composed of a source of vacuum for drawing in air, a collecting device, and a device for measuring the quantity of air sampled. Some problems associated with air sampling are:

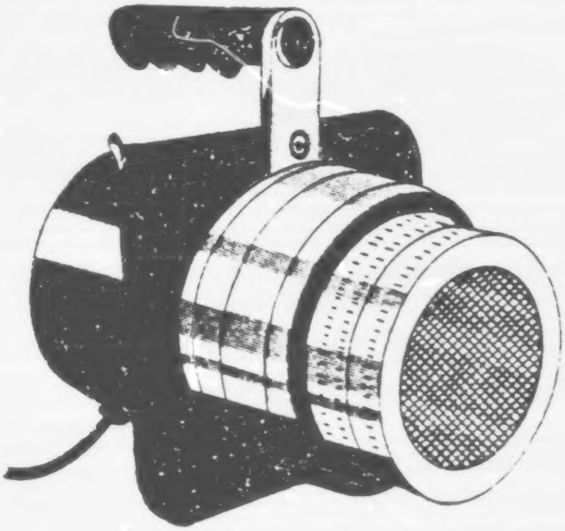
- Obtaining a representative sample of what a worker is likely to encounter.
- Obtaining a large enough sample to meet sensitivity requirements of the radiation detector.
- The choice of collecting device, which is chiefly dependent upon whether one is concerned with gaseous or particulate radiation.

AIRBORNE PARTICULATES

Widely used methods for sampling airborne particulates are filtration and impaction. For radioactive particulates, filtration is the most common method. Filtration involves the holding back of particles larger than the filter's pore size. A degree of impaction also is present in the filtration method. Impaction takes advantage of the fact that air must change directions many times while moving through the complex matrix of the filter. As the air changes course, the inertia of particles tends to make them continue in a straight line and to strike the filter, where they are trapped. This is why the filtration efficiency of a filter increases as the air flow rate decreases.

The efficiency of the air sampling system is dependent upon the efficiency of the filter, which is stated by the manufacturer for each type of filter. Choice of filter must weigh the importance of collecting small particles against the detrimental effects of the high pressure drop across the filter and the corresponding decrease in flow rate. The filter media are mounted on collection heads that vary in size from about 3/4" diameter to about 8" x 10". Proper installation of the collection heads cannot be overemphasized; if a leak occurs, the efficiency of the filter medium is lost. A typical high-volume air sampler is illustrated in Figure 18-2-10.

Figure 18-2-10. A typical high-volume air sampler.



RADIOACTIVE GAS MONITORING

The collection and analysis of radioactive gases can be extremely difficult, especially during emergency situations. Analysis of radioactive iodine is of great importance in accidents involving typical reactor- and weapons-testing operations. To collect iodine, activated charcoal cartridges often are utilized to retain the iodine as the air is drawn through the cartridge. Under ideal laboratory conditions, this method has nearly 100% collection efficiency for iodine. Radioactive noble gases – including Argon-41, Krypton-85, and Xenon-133 – also can be collected by charcoal samplers maintained at very low temperatures. Analysis of gases collected in charcoal can be made by gamma-ray spectroscopy equipment or (with iodine) by means of wet chemistry. For a very rough analysis in the field, the probe of a portable survey meter can be placed against the filter, and the measured activity can be corrected for geometry factors.

One of the easiest methods of actually taking a sample of air is grab sampling. This involves opening of an evacuated container in the atmosphere to be sampled; contaminated air is allowed to enter the container. The activity of the sample can be measured by transferring of the gas to an ionization chamber, and measuring of the ionization current due to the gaseous activity.

Continuous-flow ionization chambers also can detect radioactive gases. The most popular instrument for tritium detection in emergency situations is with a portable integrating ionization chamber with a continuous air flow. It indicates the presence of tritium, but will not give an indication of tritium concentration.

A method of measuring the amount of tritium in the air consists of drawing a sample through a bed of desiccant material such as silica gel. Tritium oxide is collected, along with the moisture in the air. In the laboratory, the moisture can be separated, recondensed, and analyzed for tritium content.

Exposure to large-volume, high-concentration clouds of noble gases constitutes an immersion dose. Radiation levels can be detected with portable radiation survey instruments, and disintegration energies of the noble gases can be used to calculate the activity present.

EMERGENCY CABINETS AND LOCKERS

Every facility that has the potential for radioactive emergencies should be equipped with emergency equipment cabinets. These cabinets should be located in areas that are expected to be accessible in the event of a radiological emergency. Such areas include reception areas or storage sheds removed from the immediate locality of expected accidents. The number, contents, and locations of cabinets depend upon the size and type of facility being considered. Equipment should be divided among, or repeated in, several locations throughout the site in order that loss of one or more cabinets in the emergency accident situation will not seriously hinder rescue or cleanup operations.

A suggested emergency cabinet inventory is presented in Table 18-2-2. The use of an inventory checklist will contribute to ensuring that the required emergency equipment will be available if the need arises.

TABLE 18-2-2. EMERGENCY LABORATORY INVENTORY CHECKLIST.

		EMERGENCY CABINET INVENTORY	
No. Required	No. on Hand	Item	Comments
		Anti-Contamination Clothing	
		Coveralls	
		Plastic suits	
		Gloves, rubberized	
		Gloves, surgeon's	
		Shoe covers, rubber	
		Shoe covers, canvas	
		Head covers, hoods	
		Full face mask with cartridge	
		Self-contained breathing apparatus	
		2" masking tape	
		Anti-fog solution	
		Radiation Detection Instruments	
		Alpha monitor	
		Neutron monitor, fast	
		Neutron monitor, thermal	
		Neutron activation foils (indium)	
		Low-energy gamma detector	
		Low-level beta/gamma detector	
		Head phones	
		High-level beta/gamma detectors	
		Particulate air samplers	
		Gas monitors	
		Filter paper	
		Charcoal filters	
		Self-reading pocket dosimeters	
		Dosimeter charger	
		Bioassay sample kits	
		TLD badges	
		Instrument repair kit	
		Contamination Control	
		Survey log	
		Survey grid maps	
		Nasal swabs	
		Swab containers	
		Smear papers	
		Glassine envelopes	
		Area access log	
		Large plastic bags	
		Small plastic bags	
		Contaminated material stickers	
		Barricade ribbon	
		Area radiation signs	
		Brown kraft paper	
		Commercial glass cleaner	
		Detergent	
		Soap	
		Towels	

TABLE 18-2-2. EMERGENCY LABORATORY INVENTORY CHECKLIST.

		EMERGENCY CABINET INVENTORY	
No. Required	No. on Hand	Item	Comments
		Misc. Materials and Equipment Flashlights with batteries Spare flashlight batteries First aid kit Notebooks Clipboards (with paper) Retractable pens Grease pencils Health physics handbook Emergency notification roster Facility emergency operating procedures NRC regional office directories Area maps	

AUXILIARY EQUIPMENT

EMERGENCY PLANS AND PROCEDURES

Every facility should have an approved emergency plan and procedures and should include a copy with each emergency supply cabinet. These emergency plans and procedures should serve as guidelines, but not as rigid requirements of emergency-team operations. (Emergency plans are discussed in detail in Module 18-6.)

RECORD BOOKS AND NOTEBOOKS

In any radiological emergency operation, proper documentation of actions taken is extremely important. Record books and notebooks should be provided for this required documentation and for maintaining a record of all data coming in from the field. An ample number of pens and pencils should be included.

COMMUNICATIONS EQUIPMENT

Radio communication equipment should be provided for communication between team personnel and, if phone lines are inoperable, communication with the "outside world."

REFERENCES AND TABLES

Data coming in from the field often must be evaluated before it is meaningful. Some references and tables that provide necessary data for calculations should be available. A copy of the Radiological Health Handbook is an example of a useful reference book.

CAMERA

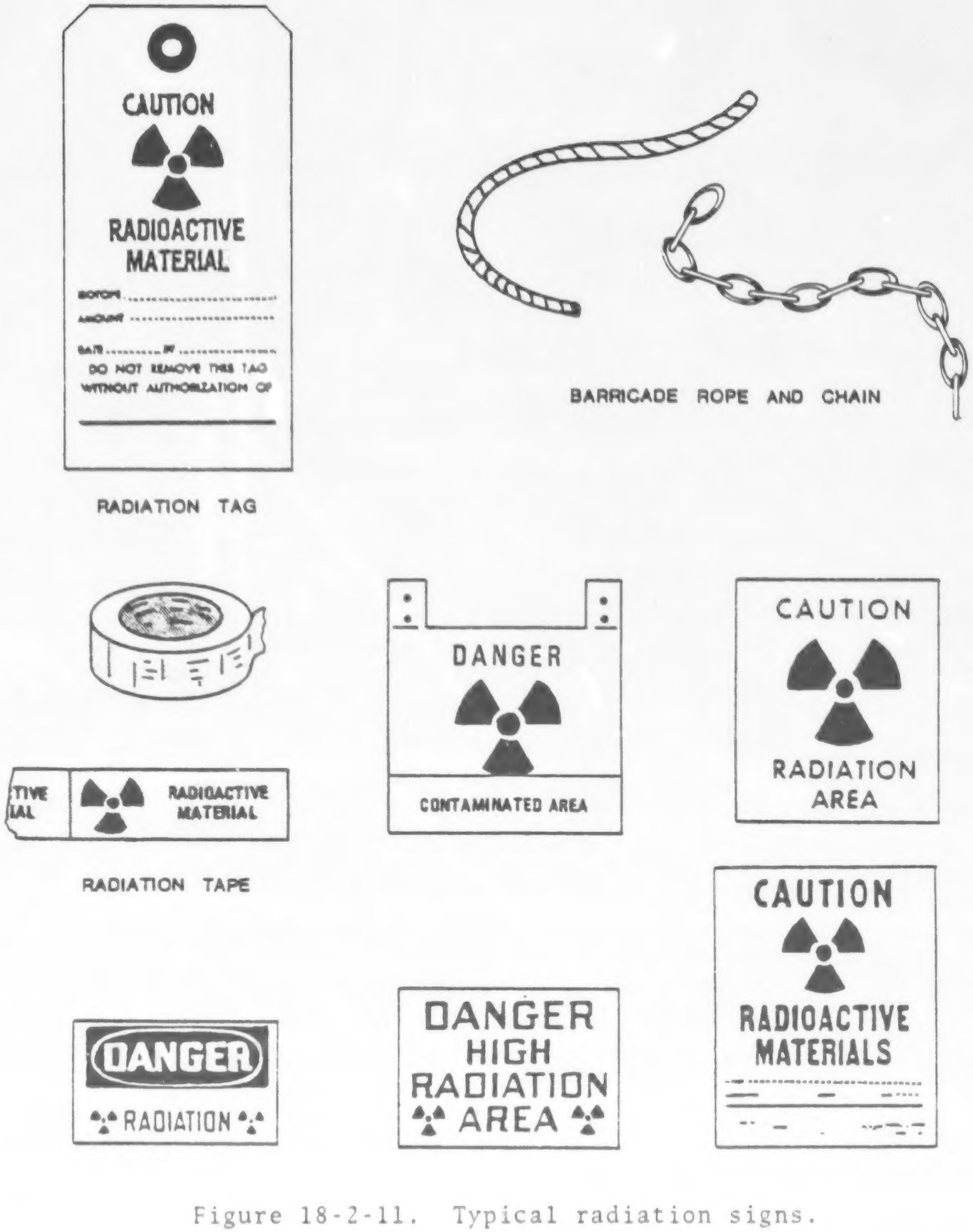
Photographic equipment may be useful as an aid in documentation of events or procedures.

RADIATION BARRICADES AND WARNING SIGNS

Equipment for marking high radiation levels and for indicating specific hazards will aid in control of personnel exposure and reduction in the spread of contamination. This type of equipment includes barricade ribbon or rope and area radiation signs. Examples of these items are illustrated in Figure 18-2-11.

Members of radiological emergency assistance teams may be called to respond to radiological accidents in any given situation. Because they must be able to respond rapidly, preparations must be made in advance for their equipment. Their materials must be packaged for transport in order that they are protected against rough handling and possible adverse weather conditions. It is recommended that the weight of any container and its contents be limited to 50 pounds.

Each member should have a minimum of one respirator and one set of anti-contamination clothing, with extra gloves, shoe covers, and headcovers. Other necessary equipment should be divided among members of the team. Film badges and extra batteries should be stored in a refrigerator near their emergency kits. If the team is responding to an accident accessible only by foot travel, a compass definitely should be included.



RADIATION TAG

BARRICADE ROPE AND CHAIN

RADIATION TAPE

CAUTION
RADIOACTIVE MATERIAL
DO NOT REMOVE THIS TAG WITHOUT AUTHORIZATION OF
TIVE
IAL
RADIOACTIVE MATERIAL
DANGER
CONTAMINATED AREA
CAUTION
RADIATION AREA
CAUTION
RADIOACTIVE MATERIALS
DANGER
RADIATION
DANGER HIGH RADIATION AREA

Figure 18-2-11. Typical radiation signs.

EXERCISES

1. List and define the three major types of respiratory protective devices.
2. Discuss the importance and use of the following equipment for the monitoring of personnel:
   a. Film badges.
   b. Criticality dosimeters.
   c. Thermoluminescent dosimeters.
   d. Self-reading pocket dosimeters.
3. Describe the major factors that should influence the technician's choice of radiation detection instruments.

MATERIALS

NOTE: The number of each of the below items required for a class depends upon the number of students that individually or simultaneously complete the procedures.

Coveralls.
Protective footwear (shoe covers, boots, etc.).
Gloves (rubber, surgeon, cotton).
Head cover or hood (cloth, plastic .
Respirator (full-face, filter, self-contained).
Wide masking tape with which to seal openings in clothing, etc.).
Personnel dosimetry (direct-reading dosimeter, extra film badge, etc.).
Survey instruments. (Select proper instrument for type of radiation involved.)

DRESSOUT PROCEDURES FOR ENTRANCE INTO A CONTAMINATED AREA

1. Select proper clothing and equipment from emergency cabinet or kit.
2. Put on coveralls, and seal the front opening with masking tape.
3. Put on shoe covers, tucking the cuffs of the coveralls inside. Tape the juncture.
4. Put on respirator; check for proper fit and operation.
5. Put on head cover of hood. Tape the hood entirely around the bottom and up the front seam.
6. Put on surgeon's gloves, and pull coverall cuffs down over the tops.
7. Wear cotton gloves if working outside of operation permits. The exterior of cotton gloves should be pulled over the coverall cuffs and taped.
8. Wear personnel-monitoring devices on upper portion of body.

PROCEDURES FOR MAKING EXIT FROM A CONTAMINATED AREA

1. Place equipment (air samplers, survey instruments, etc.) in predetermined area adjacent to the Hot Line check point for survey.
2. Remove tape and place in radioactive waste bag.
3. Be monitored by Hot Line monitor or partner for hot spots. Pay special attention to back of neck, hands, and feet.
4. Remove cotton gloves and place in large plastic bag.

5. Remove hood and place in bag.
6. Remove one shoe cover, and place the foot over Hot Line. Place shoe cover in bag.
7. Remove other shoe cover, and stand in clean area. Place shoe cover in bag.
8. Have partner or Hot Line monitor to assist in the removal of the respirator; place respirator in bag.
9. Remove surgeon's gloves and place in bag.
10. Remove coveralls.
11. Resurvey personnel clothing and effects for contamination.

DATA TABLE

None.

REFERENCE MATERIALS

A Guide to the Selection, Training, and Licensing or Certification of Reprocessing Plant Operators, Vol. 1, ORNL/TM-5323. Oak Ridge, TN: Oak Ridge National Laboratory, 1976.

Moe, H.J.; Lasuk, S.R.; Schumacher, M.C.; and Hunt, H.M. Radiation Safety Technician Training Course, ANL-7291, Rev. 1. Prepared for Argonne National Laboratory, Argonne, Illinois. Springfield, VA: National Technical Information Service, U.S. Department of Commerce, 1972.

Purington, Robert G. and Patterson, H. Wade. Handling Radiation Emergencies. Boston: National Fire Protection Association, 1977.

U.S. Atomic Energy Commission. Radiological Emergency Operations, TID-24919.

National Safety Council. Fundamentals of Industrial Hygiene, 1971.

TEST

1. What are two benefits of the wearing of two pairs of anti-contamination coveralls?

2. Discuss some factors to be considered when proper anti-contamination gloves are selected.

3. List the steps taken for proper removal of anti-contamination clothing.

4. List two situations in which a chemical-cartridge respirator would be inappropriate.

5. Give some advantages and disadvantages of air-supplied breathing apparatus.

6. How can one test a gas mask for leaks?

7. Under what circumstance should a detection instrument not be completely covered with plastic when a contaminated area is entered? Explain.

8. What type of detection instrument should be used in an emergency situation involving beta radiation? alpha radiation?

9. Explain why two pocket dosimeters should be worn for monitoring during radiation emergencies.

10. What type of personnel monitoring device is used to provide a permanent record of radiation exposure?

11. Without including anti-contamination clothing, respiratory equipment, or radiation monitoring or detection devices, list five other items useful during radiological emergencies, and briefly explain their use.

12. What is the major consideration when choosing the type of air-sampling equipment?

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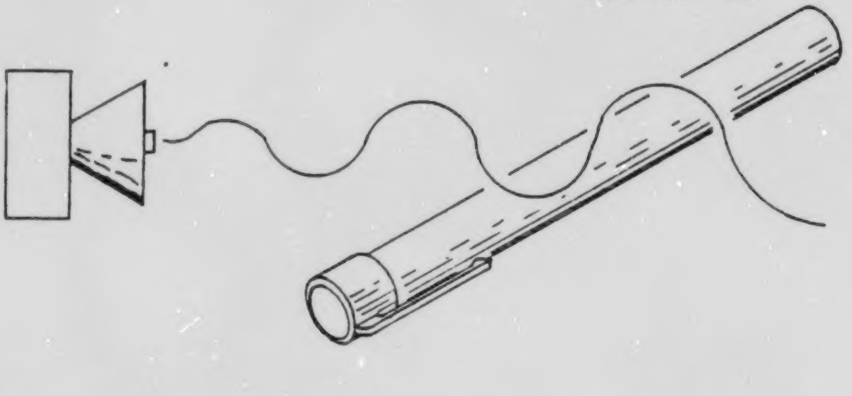
NUCLEAR TECHNOLOGY

MODULE 18 - 3

SURFACE CONTAMINATION - DECONTAMINATION

RADIOLOGICAL
EMERGENCIES

COURSE 18



CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

COURSE 18 RADIOLOGICAL EMERGENCIES

Module 18-1	General Procedure for Radiological Emergencies
Module 18-2	Emergency Equipment for Nuclear Facilities
Module 18-3	Surface Contamination — Decontamination
Module 18-4	Criticality Control
Module 18-5	Control of Radiological Hazards
Module 18-6	Emergency Planning for Nuclear Facilities
Module 18-7	Emergency Drills for Nuclear Facilities

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INTRODUCTION

Each organization involved with the use of radioactive materials must continually evaluate all phases of its operation. Many organizations, although capable of handling most industrial-type accidents, must place additional emphasis upon the handling of situations or accidents that involve radioactive materials; specifically, upon the control of radioactive contamination and the accident-recovery operations that require decontamination of people, places, and things.

What is radioactive contamination? In very simple terms, it is the presence of radioactive materials in an undesirable location. More important than the presence of contamination are its effects in terms of health hazards; for example, inhalation of materials results in an internal exposure to radiation.

What is decontamination? Decontamination is the removal of the radioactive materials of concern to a more desirable location. The purpose of decontamination is directly related to the health hazards associated with radioactive contamination. Thus, high levels of radioactive contamination is a problem that could affect the health and safety of the radiation worker and of the general public. Decontamination is the removal of, or at least control of, the radioactive materials for the purpose of preventing them from being inhaled, ingested, or taken into the body through access from open wounds or cuts. If a sufficient quantity of gamma radiation is present in the contamination, the hazard of external radiation exposures must be considered. The problems associated with radioactive contamination and decontamination are not insurmountable, but in most cases are solved easily by the well-trained technician.

MODULE PREREQUISITES

The student should have completed Course 1, "Radiation Physics"; Course 2, "Radiation Protection I"; Course 11, "Radiation Detection and Measurement"; Course 17, "Radiation Protection II"; and the previous two modules of this course.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Identify types of radioactive contamination.
2. Perform a detailed contamination survey, and evaluate the data in terms of associated health hazards.
3. Explain the principles, techniques, and procedures for decontamination.

THE RADIATIONS ASSOCIATED WITH RADIOACTIVE CONTAMINATION

There are three types of radiations, which either separately or in a combination always are present in a radioactive contamination incident. These radiations are alpha, beta, and gamma; each exhibits its own individual characteristics of behavior and associated health hazards. Radioactive materials that gain access into the body become an internal hazard. Internal radiation hazards associated with radionuclides decaying by alpha and beta emissions are the most dangerous because their specific ionization is very high; for instance, the radionuclide polonium emits an alpha particle whose energy of 5.3 MeV is transferred to the tissue through which it passes in a very short length of travel.

Gamma radiation is electromagnetic radiation of nuclear origin and is similar to X-rays. When of sufficient energy, gamma rays have the ability of deep penetration into tissue. Thus, gamma radiation presents and external radiation hazard because no internal organ of the body is beyond their penetrating range or damaging powers.

Beta radiation consists of negatively charged particles emitted from the nucleus of an atom. The mass and charge of the particles are equal in magnitude to those of electrons. Beta radiations constitute both external and internal hazards. Beta particles that have sufficient energy to penetrate the basal layers of skin are considered external hazards, and all beta particles deposited within the body present an internal hazard.

Alpha radiation consists of a helium nucleus that contains two protons and two neutrons and that possesses a double positive charge. Alpha radiation will penetrate only a limited amount of material: A single sheet of typing paper is completely sufficient to absorb most alpha particles. Since alpha particles lack the power to penetrate the outer layer of skin, they do not present an external radiation hazard.

HAZARDS OF ALPHA EMITTERS

Because of their relatively large mass and double positive charge, alpha particles will lose their energy very rapidly in the medium through which they pass. An alpha particle with an energy of 4 MeV has a range in tissue of only a few hundredths of a millimeter; however, radionuclides, which are alpha emitters, cause the most severe hazards of internal exposures. When deposited in a vital organ inside the body, they cause great biological damage because of their high energies and high specific ionization.

The nuclear industry uses several alpha-emitting radionuclides, the most common of which are plutonium-239, polonium-210, natural and enriched uranium, and radium-226. Plutonium-239 emits alpha particles having an average energy of 5.15 MeV and a range of about 0.04 millimeters in water or soft tissue. It also emits several weak X-rays with energies from 10 to 22 keV. ^{239}Pu deposits predominantly in the skeleton, where many years later it may produce bone disease (including cancer). Lung deposition presents the greatest internal hazard to the body because approximately 90 percent of the inhaled dose is retained in the lung, thus increasing the probability of lung cancer. Its absorption is potentially the most important means of entry into the body, and may reach 1 to 10 percent of the inhaled dose, depending upon such parameters as particle size and solubility.

The permissible body burden of ^{239}Pu is only 0.04 μCi. This is an extremely small amount of material equivalent to only 0.625 micrograms or approximately 8.75×10^4 alpha disintegrations per minute. Once fixed in the body, ^{239}Pu is excreted quite slowly: About 200 years would be required to eliminate one-half of the body burden. Polonium-210 is an example of a potential internal hazard. It emits highly-ionizing alpha particles of 5.3 MeV energy and has a radiological half-life of 138 days. The critical organs are the spleen and kidneys. Americium-241 is another example of a potential internal hazard. It emits highly-ionizing alpha particles with an average energy of 5.4 MeV and has a radiological half-life of 458 years. The critical organs are the kidneys and bones. Americium is one of the more common radionuclides used by several industry disciplines: Americium-beryllium neutron sources are good examples.

Uranium-238 emits 4.4-MeV alpha particles. The critical organs are the kidneys, in which soluble uranium exhibits an effective half-life of 15 days. The permissible body burden for the kidney is 5×10^{-3} μCi, a relatively large amount of natural uranium (about 40 milligrams). It is unlikely that a person would get this much material into his body; and if he did, it probably would be chemically toxic before the effects of radiation would become apparent. Enriched uranium is a more serious radiological hazard than natural uranium.

Radium-226 and its daughter products emit alpha particles having an average energy of 4.8 MeV. This radioisotope is a bone seeker and presents a very serious internal radiation hazard because it has an effective half-life of approximately 44 years. The permissible body burden for bone is 0.1 μCi (or 0.1 microgram). Radium in equilibrium with its daughters frequently is used as a gamma source.

HAZARDS OF BETA EMITTERS

Since beta particles are lighter and have less charge than alpha particles, they experience a longer path of travel with less specific ionization.

Accordingly, the relative biological effect of beta particles is much less than that caused by alpha radiation; for example, the absorbed energy from beta radiation must be approximately 20 times greater (per unit mass of tissue) than that of alpha radiation to produce the same damaging effect. Both alpha- and beta-emitting materials are primarily internal radiation hazards, although beta radiation may represent an external hazard when the energy is sufficient to penetrate the dead layer of skin. External beta burns can be extremely painful and slow to heal.

Few radionuclides are pure beta emitters such as Strontium-90, a fission product and a pure beta emitter that decays with a radiological half-life of 27.4 years. Its radioactive daughter, Yttrium-90, is also a pure beta emitter. Strontium-90 in equilibrium with yttrium-90 becomes affixed in the bone and is a very dangerous internal radiation source.

Iodine-131 is a fission product and a beta-gamma emitter. It ejects beta particles with average energies of 0.22 MeV. The effective half-life is 7.6 days. The critical organ for this radioisotope is the thyroid. This radioisotope

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is not as dangerous as strontium-90 because of its short half-life and because it would have to be ingested or inhaled in large quantities to be a serious hazard.

PREVENTION OF INTERNAL RADIATION HAZARDS

The potential for internal radiation hazards is always associated with radioactive contamination; therefore, the most effective means for the prevention or reduction of these hazards is the prevention and control of radioactive contamination. Good radioactive materials handling techniques and protective devices and equipment — for instance, a radiochemistry hood equipped with a filtered ventilation system — will assist with the prevention of airborne contamination. Exhaust air must be filtered before it is exhausted to eliminate the release to the environment of radioactive particulates that could become a health hazard to the general public. Protective clothing should be worn in order that permanent clothing does not become contaminated; this procedure helps to limit the spread of contamination. To prevent the inhalation of radioactive materials, respirators should be available for emergency operations in areas in which radioactive material could become airborne. Eating and smoking should be prohibited where radioactive materials are handled to reduce the possibility of ingestion hazards.

The single most important phase of radioactive contamination prevention, is the prior and proper planning of the operations that will result in the elimination and control of radioactive contamination and associated hazards.

The spread of radioactive contamination may be minimized at several points. Containment, or the restriction of radioactive materials to specified areas, is the first line of defense. Containment is achieved by the adoption of operating techniques and laboratory methods best suited to the radionuclides of concern, selection of proper equipment, and adherence to good handling practices.

OPERATING TECHNIQUES AND EQUIPMENT

The choice of equipment and operational techniques for handling radioactive materials is an extremely important part of contamination control. Considerations of the following items during the planning phase of the operation will be beneficial in the prevention of radioactive contamination.

- Quantity of Radioactive Material Used. The quantity of radioactive material used should always be as small as practicable, and materials of low toxicity should be chosen whenever possible.
- Protection of Working Surfaces. During radiochemical operations, the working surface should be covered by either metal trays or a layer of disposable absorbent material to soak up spilled liquids. Blotting paper or "diaper" paper (heavy absorbent paper backed with impervious material such as plastic sheeting) are used extensively. The latter is preferable, as it prevents liquids from reaching the bench top.
- Dummy Runs. A worthwhile procedure is to carry out a complete dummy run with nonradioactive materials before any manipulation of open radioactive sources

is undertaken. In this way, unexpected difficulties may be discovered, weaknesses in equipment detected, and the procedure modified accordingly.

- Uses of Containers for Radioactive Liquids. Reliance should not be placed on single containers; suitable drip trays or double containers should be used as a secondary measure of protection, and they should be capable of holding the entire contents of the primary containers.
- Operational Equipment. Potentially contaminated equipment should never be handled with bare hands, and pipettes must never be operated by mouth suction. Glass blowing in active area or on contaminated equipment should be accomplished with special techniques that avoid blowing by mouth.

The selection of equipment for working with radioactive materials depends largely upon the quantity of the material and their associated hazards. In any case, the use of radiochemical hoods and glove boxes is highly recommended.

Laboratory operations accompanied by the evolution of radioactive fumes or gases require the use of radiochemical hoods. The inner surfaces of the hoods should be of nonporous material such as stainless steel. The surfaces may be covered with a strippable paint to permit easy decontamination.

The glove box is a totally enclosed chamber in which alpha emitters and low-energy beta sources can be handled safely. The great advantage of the glove boxes, apart from the obvious one of confining contamination within a totally enclosed space, is the small air supply involved, in comparison with the large air flow necessary in the radiochemical hood, to prevent escape of radioactivity into the working atmosphere. The disadvantages of glove boxes are the extra time and labor involved and the difficulties of working inside them, but they are indispensable for work with dry powders of highly toxic materials.

All equipment used for the handling of radioactive materials must be segregated and used only for this work. The equipment should be marked "for radioactive use only" to prevent its use for other purposes. This segregation is particularly important for glassware and handling equipment such as tongs and gloves that can transfer contamination easily from the approved handling area to the open laboratory.

All personnel working in radiation areas must wear the prescribed protective clothing. The degree of clothing change considered necessary depends upon the level of the radioactivity and the types of operations. Tracer studies utilize very low levels of radioactivity; however, a standard laboratory coat and gloves should be worn, and a compulsory shoe change is recommended. In working with intermediate levels of radiation, laboratory costs and a change of shoes should be regarded as compulsory, and a complete change of clothing may be required in place of the laboratory coat. Associated support facilities range from clothing racks in the laboratory to a completely equipped change room.

Individuals working in more hazardous regions such as in the area of hot cells require a greater degree of protection. They should not work in a radioactive area without the appropriate change of clothing, and this clothing should not be worn outside the area. If it is necessary for protective clothing to be worn outside a laboratory that potentially is highly contaminated, a surrounding control, or buffer, area should be established and passage beyond this area restricted without a clothing change. To avoid hand contamination, gloves always should be worn when radioactive materials are handled. An acceptable type of glove for this purpose is the standard tight-fitting surgical glove made of thin latex rubber. Surgical-room techniques should be employed when putting on and taking off gloves, in order that the inside surfaces will not be contaminated.

Unessential personal items should not be taken into the work area; for example, food, drink, or smoking materials should be left outside the area. Nothing should be placed in the mouth while working in such areas.

Cleanliness in a radioisotope laboratory goes beyond mere visible cleanliness. It involves on-the-spot monitoring of the laboratory equipment in use and personnel and prompt decontamination when necessary. Working surfaces, floors, and all other surfaces in the area should be checked regularly, and monitoring should be extended to cover all protective clothing. All people and equipment leaving the work area must be monitored for radioactive surface contamination.

The mental attitude of the worker plays an extremely important part in contamination control and radiation protection. All personnel who work in a radioactive area should wash and monitor their hands and feet before leaving, particularly at the end of the day and before eating. Gloves should be monitored regularly, and personal clothing worn from the facility should be checked periodically for radioactive contamination.

The use of proper operating techniques must be supplemented by cleanliness and good housekeeping, which will minimize the spread of contamination and will prevent the buildup of contamination to serious levels.

Dust-raising methods such as dry sweeping should be avoided. A separate set of properly marked cleaning equipment should be kept solely for use in radioactive work areas.

MANAGEMENT OF SPILLS

In the event of a spill or accident that involves the contamination of an area, personnel protection and the immediate confinement of the contamination are of primary importance. When a spill occurs, a standardized approach, such as the procedure outlined in Table 18-3-1, must be followed.

TABLE 18-3-1.
STANDARDIZED APPROACH FOR THE MANAGEMENT OF SPILLS.

Prevent Spread of Contamination

1. Close doors and windows.
2. Turn off fans, air conditioners, and other such ventilation if possible.
3. Close ventilation ducts if possible.
4. Evacuate the room, leaving shoes and outer garments at door.
5. Lock door(s), and seal cracks with tape.

The spill is now confined, and cleanup can be accomplished according to approved procedures.

Decontamination

1. Monitor spill area to determine the extent and level of contamination.
2. Work out a specific plan for decontamination.

RADIATION DETECTION AND MEASUREMENT BY INSTRUMENT AND SMEAR MONITORING

Monitoring is the determination of the presence and extent of ionizing radiation and radioactive contamination. Monitoring provides information for radiation protection and may be divided into two general types: (1) area monitoring, which pertains to a specific area, building, room, etc.; and (2) personnel monitoring, which is concerned with personnel - their bodies, clothing, and other personal items.

The main difference between these two types of monitoring is in their objectives. Area monitoring is a preventive measure; and its purpose, in most instances, is to determine the levels of radiation intensity or the presence of radioactive contamination. Instantaneous information is desired in order that prompt action may be taken. The intent of personnel monitoring, on the other hand, is to provide an indication of accumulated exposure and the detection of radioactive materials that either could be transferred to other items or gain access to the body via ingestion. By the time results of personnel monitoring are obtained, it is too late for preventive action and steps of corrective action are required to prevent the recurrence of a hazardous condition. If personnel monitoring discloses an overexposure, the prescribed measures will be corrective or, in some cases, curative in nature.

Personnel selected to perform monitoring operations must have full knowledge of the capabilities and limitations of the various monitoring devices and techniques and must be able to interpret instrument readings correctly. Familiarity with the necessary safety precautions is essential. In addition, they must be able to make recommendations for the elimination of existing or potential hazards indicated by the monitoring operation. Much of this knowledge is acquired through on-the-job instruction and participation in monitoring operations.

AREA MONITORING

In area monitoring, detection and measuring instruments are utilized to determine the level of radioactivity in a specified area. The various types of area monitoring include source, surface, air, liquid, regional, and emergency monitoring.

Area monitoring may be continuous, periodic, or circumstantial. Continuous monitoring is desirable for locations at which radiation hazards are likely to develop at any time. When the occurrence of hazards is less probable, periodic monitoring may suffice; in this case, the frequency of monitoring depends upon the radiation levels common to the area, the extent to which the area is occupied, and various other local considerations. When all pertinent factors have been evaluated, monitoring schedules will be established for each specific location. In unmonitored areas, surveys may be undertaken at any time upon the discretion of health physics personnel or upon the request of a worker or a supervisor. Monitoring operations during decontamination, waste disposal, and the opening of radioactive shipments are examples of circumstantial monitoring. A worker who suspects that conditions in an area may be hazardous should notify a supervisor, who will request health physics personnel to make a survey.

Monitoring is most effective when preliminary knowledge of conditions within the area is available. Such knowledge should include the following items:

- Type, amount, and location of radioactive material.
- Operations performed within the area.
- Potential hazards associated with the operation.
- Effects of a mishap on surrounding areas.
- Locations of possible contamination, which include "hot" drains, glove boxes, storage containers, etc.

This information will aid in the making of quick evaluations in the event of a radioactive spill. It also will provide an indication of the proper instruments, monitoring techniques, and protective clothing and equipment needed by personnel engaged in the monitoring operation.

In actual practice, the first readings to be taken in any area are background counts, which then are listed on a floor plan of that area and used as a reference for future surveys. Since background counts will fluctuate over a period of time, it is recommended that such readings be taken at regularly scheduled intervals and that appreciable variations should be noted.

SURFACE MONITORING

Surface monitoring is the monitoring of all sufaces that conceivably could become contaminated. Floors, walls, bench tops, storage areas, radioactive waste containers, and shipping containers are typical areas and items that require surveys. Radioactive contamination, defined as the deposition of loose radioactive material, which, by nature of its location, is hazardous to personnel or undesirable for technical reasons, must be controlled; otherwise, it may cause an internal and/or external radiation hazard and may interfere with experiments in progress. Surface monitoring is designed to detect all radioactive contamination that other area monitoring operations cannot reveal.

The presence of surface contamination is determined by two methods: (1) area surveys with radiation-detecting instruments: and (2) samples taken from various surfaces by wipes or smears. Both operations are intended to locate contamination promptly to obtain a reliable measurement of the degree of contamination present. Special techniques have been developed for the performance of each phase.

The first phase of surface monitoring is the scanning procedure with a sensitive detecting instrument, the purpose of which is to locate contamination and to determine its extent. Scanning should not be confused with the measurement process, which determines the amount of contamination present. Suitable instruments for scanning include the end-window Geiger-Müeller detector for beta radioactivities or a thin NAI(tl) scintillator for very low-energy gamma radiations. Although scanning is a rapid operation, it, nonetheless, must be thorough. Spots that are difficult to reach with instruments must not be overlooked; for example, corners, recesses, high shelves, etc. A poorly conducted survey may miss these locations at which contamination is most likely to occur. All work areas should be assumed contaminated until survey results are evaluated. When instruments of slow response time (for example, ionization chambers) are utilized, the scanning speed should be adjusted accordingly.

If scanning reveals that a particular surface is contaminated, wipes should be taken to ascertain whether or not the contamination is removable. A wipe usually is obtained by the rubbing of a handful of facial tissue or cheesecloth over the surface in question. When a survey is performed for beta-gamma radioactivities, the wiping material should be moistened. Wipes are not intended to provide accurate measurements, although an experienced monitor usually can estimate the degree of contamination on the basis of a wipe count.

Measurements of contamination, the second phase of surface monitoring, can be made directly by portable detection instruments, or smears may be taken from contaminated surfaces and their activity measured by a counter (a device that detects radioactive disintegrations and registers the total count taken over a period of time). Precise results are difficult by either method because of indeterminable factors such as geometry, penetration depth, and self-absorption.

The technician obtains a smear by rubbing a paper disc over the surface to be checked. The rubbing is gentle and in back-and-forth motions. The standard material for collection of the smear is a dry piece of filter paper (such as Whatman No. 40 or 50 "acid hardened"), that has a diameter of approximately two inches. The smear should cover an area of about 100 square centimeters (4 or 5 inches square). Rubber gloves or finger cots must be worn to protect the hands from contamination when a smear is taken.

Some basic monitoring techniques enhance, or add validity to, the smear survey. The standard practice for determining concentrations of radioactive surface contamination is the measurement of radioactivity per unit area; that is, disintegrations per minute per 100 square centimeters (dpm/100 cm^2). As previously mentioned, the smear should cover an area of 4 or 5 square inches; however, this is not to say that the smear is to be confined to one compacted area. When distributed over the region of concern, the 100 cm^2 area will be more reflective of the contamination present. Two examples of smear areas are presented in Figure 18-3-1.

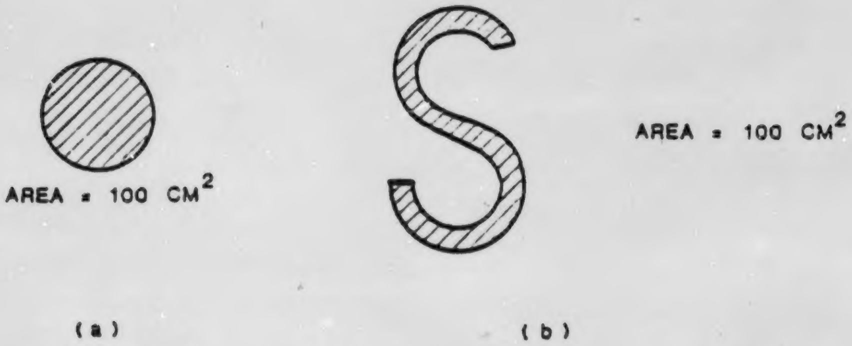

Figure 18-3-1. Smear sample collection.

The smear area illustrated in Figure 18-3-1b will distribute the 100 cm^2 over a larger region of interest and should be utilized in the survey of floors, bench tops, and large pieces of equipment. The smear area in Figure

18-3-1a should be used for the smearing of confined areas, small pieces of equipment, and storage containers.

RADIATION-DETECTION INSTRUMENTS

A variety of radiation-detection instruments should be available for contamination surveys. The need for these different instruments is directly related to the behavior of the different types of radiation; for instance, alpha radiations can be stopped with a single sheet of typing paper, which fact indicates that detection of alpha radiation requires an instrument that will allow penetration of the alpha particle into its detector.

The examples of survey instruments presented in this module are for illustrative purposes only. References to these instruments should not be construed as an endorsement.

THE EBERLINE MODEL PAC-4G GAS PROPORTIONAL ALPHA COUNTER

The PAC-4G is a portable, battery-operated instrument used for the detection and measurement of alpha radiation (Figure 18-3-2). It is equipped with a gas-flow, proportional type detector, and the count rate is read out by the presentation.

This presentation eliminates all scale switching and multiplying factors, yet retains linear increments within each decade. Four decades are covered using two meter movements to yield a scale length of about 1.5 inches per decade, which gives maximum readability and ease of interpretation.

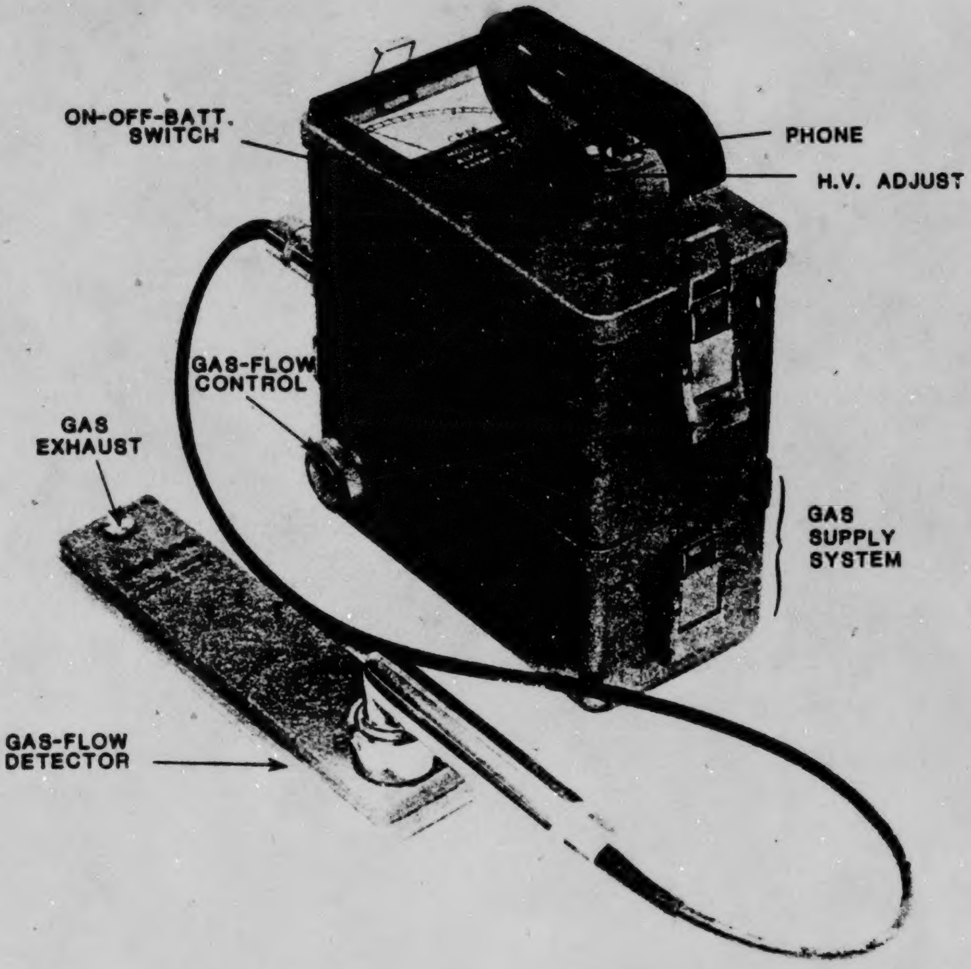
ON-OFF-BATT. SWITCH
PHONE
H.V. ADJUST
GAS-FLOW CONTROL
GAS EXHAUST
GAS SUPPLY SYSTEM
GAS-FLOW DETECTOR

Figure 18-3-2. Eberline Model PAC-4G Gas Proportional Alpha Counter.

Full-scale reading for the four decades are 500, 5K, 50K, and 500K counts per minute (cpm) respectively. Calibration is such that the meter reads the 2π value of a 1" diameter ^{239}Pu source.

Aural monitoring capability is included by means of a connector on the front panel. Either a headset or an EIC Model SK-1 speaker must be used.

The detector (probe) is connected to the instrument case by a special cable that delivers voltage to the probe; that acts as a carrier for the signal pulse from the anode; and that provides a passage for propane gas from a gas cylinder (in the lower half of the case) to the probe. The probe is rectangular and has a thin (0.85 mg/cm^2), aluminized mylar face with a sensitive area of approximately 61 cm^2. The internal anode consists of a single wire (0.001 inch in diameter) fashioned in a rectangular loop around four small insulated posts. This wire gives the effect of a double anode. An exhaust valve atop the probe allows propane gas to escape and maintains pressure inside the probe at slightly greater than ambient.

The detector, when in a radioactive field, generates electrical pulses. These pulses are coupled into an amplifier, and after amplification they are applied to a pulse height discriminator. If they are of sufficient amplitude, they cause the binary to change states. The square wave output of the binary is applied to the driver. This converts the square wave frequency into a proportional d.c. current, which deflects the meters. Thus, the meter reading is proportional to the intensity of the radioactive field at the detector.

Monitoring procedures depend greatly on the situation at hand. Therefore, no specifics will be given. In general, the detector must be held within 1/4 inch of the surface being checked. It is most consistent placed in contact with the surface, but this has the risk of puncturing or contaminating the face. Both the BATTery check and the check source should be used periodically to assure proper operation.

Calibration probably will be required when the instrument is moved from one altitude to another.

Operation and Maintenance

Operation and maintenance of the Model PAC-4G are outlined in Tables 18-3-2 through 18-3-5, which should be studied thoroughly.

TABLE 18-3-2. CONTROLS AND CONNECTORS OF THE MODEL PAC-4G GAS PROPORTIONAL ALPHA COUNTER.

EXTERNAL CONTROLS AND CONNECTORS

1. Switch: Three-position switch turns instrument OFF, ON or to BATTery check.
2. H.V. ADJUST: controls magnitude of high voltage applied to the detector. Clockwise rotation increases voltage. Hash marks around control are for reference.
3. PHONE: for connection of headset, speaker, or external scaler.
4. Detector Connector: for connection to the detector.
5. Gas Flow Control: This three-position control combines the functions of turning the gas on and selecting one of two gas flow rates. In the OFF position, the gas flow is blocked. In

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the FLUSH position, there is a high flow rate to flush the air from the probe before use.

The OPERATE position provides a low flow rate to maintain the counting gas in the probe during use.

INTERNAL CONTROLS

L. Calibration Controls: four controls to adjust the meter reading to agree with alpha calibration sources.
2. Sensitivity Control: 20-turn control mounted on P-202 card adjusts the input sensitivity.
3. Gas Pressure Control: screw adjustment which controls gas pressure at regulator output. (See Figure 18-3-3.)

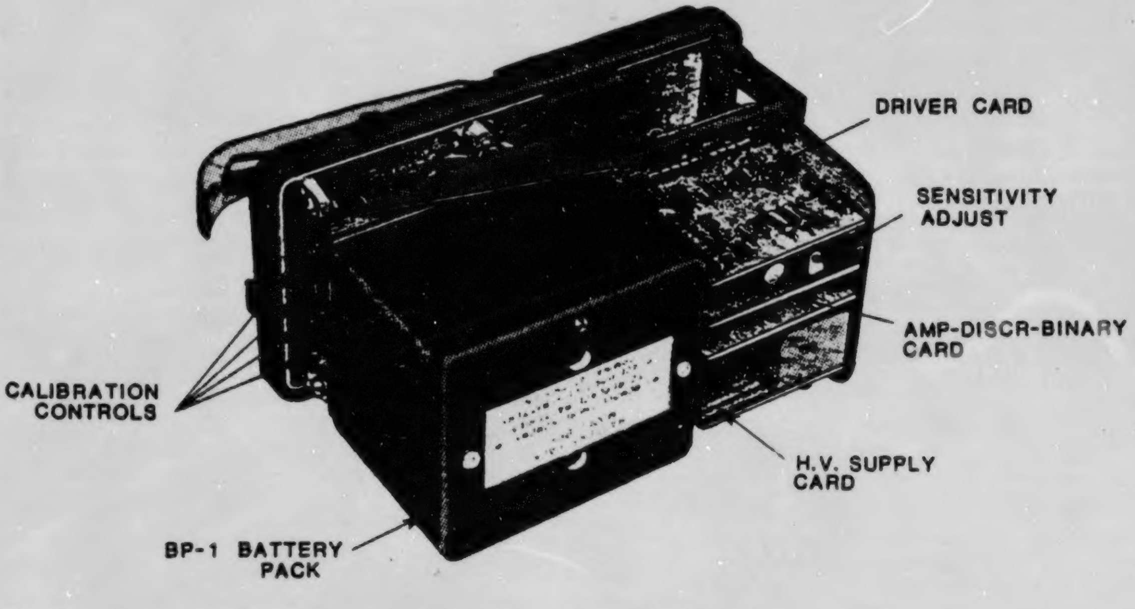

DRIVER CARD
SENSITIVITY ADJUST
AMP-DISCR-BINARY CARD
CALIBRATION CONTROLS
H.V. SUPPLY CARD
BP-1 BATTERY PACK

Figure 18-3-3. Model PAC-4G interior controls.

TABLE 18-3-3. OPERATION OF THE MODEL PAC-4G GAS PROPORTIONAL ALPHA COUNTER.

1. STARTING: Rotate the Gas Flow Control to the FLUSH position. Turn the switch to the BATTery check position, and the left pointer (black) should read in the green area. Release the switch, and it will return to the ON position. After approximately 2 minutes of flushing time, rotate the Gas Flow Control to the OPERATE position.
2. OPERATION CHECK:
    a. Remove the face protector from the detector. CAUTION: The detector face is very thin and easily punctured. DO NOT set the detector on sharp objects.
    b. With AC-21 Alpha Probe: Place an alpha check source against the face. The instrument should read the approximate value of the source.
    c. With AC-21B Beta Probe: Two readings may be checked with the optional CS-4 check source. One is with one end of the source covering one window only; the other, with the source lengthwise in one window.
3. GAS FLOW CHECK: Gas flow is essential to proper instrument operation and may be checked by flame height at the probe exhaust. VENTILATE the area around the probe if it has been stationary, and light the exhaust. Flame height should be approximately 3/4" in the operate position.

4. INTERPRETATION OF INDICATIONS:

a. Meter Indication: Reading of the LIN-LOG presentation is easy; merely read the pointer that is "on scale." The black pointer is read up to 5K cpm, above which it disappears from view and the red pointer is read. The fluctuation of the pointer is normal and is caused by the random nature of radioactive emissions. Watch the pointer long enough to obtain the average reading.

b. Phone: Using an earphone a click will be heard for each event counted. With a speaker, only one-half the number of clicks will be heard. This number is less than the meter reading because the detector efficiency is less than 100% of 2π.

TABLE 18-3-4. CALIBRATION OF THE MODEL PAC-4G GAS PROPORTIONAL ALPHA COUNTER.

1. METER CALIBRATION: Sections 1 and 2 of the driver combine to deflect meter one and sections 3 and 4 to deflect meter two. The calibration controls adjust this combination for the proper meter reading vs. input count rate. Each pair of sections and meter is completely independent of the other.

The first control (R2 and R4, respectively in Figure 18-3-3) adjusts the slope of the meter current vs. frequency line for both sections. The second control (R3 and R5, respectively) adjusts the point at which the lower frequency section saturates. This saturation forms a stable base upon which the higher-frequency section operates.

2. GAS FLOW ADJUSTMENT: The proper gas flow, measured by probe exhaust flame height, is approximately 3/4" in the OPERATE position and 2" in the FLUSH position. First adjust the OPERATE position, using needle valve 1; then adjust the FLUSH position, using needle valve 2.
3. SENSITIVITY ADJUSTMENT (See Figure 18-3-3): This adjustment is not critical since the high voltage will compensate for a wide range of settings. However, if set too sensitive, the instrument is susceptible to noise; and if set too insensitive, linearity of the detector operation is affected. Optimum setting is about 2 millivolts, which can be approximated by two counterclockwise turns from extreme clockwise rotation.
4. HIGH-VOLTAGE (H.V.) ADJUSTMENT (See Figure 18-3-2): The proper setting for the high voltage is operation on the flat portion of the plateau, below the noise threshold.

   The best method of arriving at this setting is to determine the plateau for the instrument and to set the voltage accordingly. Place a source under the detector, vary the voltage, and read the count rate. Plot cpm vs. voltage and pick a voltage setting in the middle of the plateau. (Refer to the manufacturer's manual for typical plateaus.)

NOTE: Connect voltmeter to contact A (front contact) of the H.V. supply card.

An electrostatic voltmeter should be used to read the high voltage; however, if one is not available, refer to the radial marks around the H.V. ADJUST control. Always start at the low end and increase voltage.

An expedient method of setting high voltage to the alpha plateau is to expose the probe to a beta or gamma source; to increase voltage until the instrument just starts counting; then to decrease the voltage approximately 100 volts (one radial mark) from that point.

5. CALIBRATION TO SOURCES: After the proper voltage is set, the instrument can be calibrated. Four standard sources are required, one for each decade (EIC Model S94-4 source set, or equivalent for alpha).

NOTE: The AC-21B may be calibrated using alpha standards if beta standards are not available. Turn the high voltage down to the alpha plateau for calibration, then back up to the beta plateau.

TABLE 18-3-5. ROUTINE MAINTENANCE FOR MODEL PAC-4G ALPHA COUNTER.

Step	Maintenance Procedures
1.	Blow dust from instrument case and internal components.
2.	Visually check wiring and components to locate any broken or dirty contacts.
3.	Tighten screws and nuts; do not change the high voltage, discriminator, or scale-calibration potentiometers.
4.	Inspect battery-cover plate and spring contact to ensure proper connection.
5.	Check probe face for punctures. If any are found, inspect anode wire for damage, and repair punctures or replace probe face.
6.	Run plateau curve of detector voltage versus cpm. (Discriminator should be fully clockwise in its most sensitive position.)
7.	Adjust needle valves for proper gas flow. If the gas bottle is empty, it may be changed by removing the bottom half of the instrument case and unscrewing the gas bottle. If there is an audible "pop" when the bottle is removed, it has sufficient gas. An empty bottle can be identified by its weight difference when compared to a full one. A new bottle simply is screwed into place.
8.	Calibrate with standard sources. Check beta sensitivity with a beta source (not necessarily a standard source).

Probe Contamination

Contamination of the probe occurs when radioactive material adheres to the probe face during monitoring. The contamination may not be visible, but, nevertheless, may be sufficient to give a reading. The probe face is extremely fragile and easily punctured; therefore, great care must be exercised during decontamination.

Contamination normally can be removed by a gentle wash with cotton that contains an alcohol and water solution. If water gets inside the probe, it can short the anode, in which case the probe must be dried out before it will be operable. A less preferable means of decontamination is the gentle wiping of the probe with clean cotton or a soft (camel hair) brush. If the probe cannot be decontaminated, it should be changed.

Should the probe face be punctured during use in the field, and should the situation demand its continued use, a small hole in the probe face can be patched with a small piece of masking tape or cellophane tape. The tape will shield alpha particles and the sensitive area will be reduced accordingly.

If alpha radiation is to be measured in an area also contaminated with beta radiation, the instrument must be checked for beta sensitivity. The surface being monitored is covered with a sheet of clean paper. If a meter indication is noted, either the probe is contaminated or the instrument is measuring beta activity. If a uniform reading is obtained when the probe is held in the air, it has become contaminated. If necessary, monitoring can continue if the contamination is subtracted from the total counts. If the instrument is measuring beta radiation, the discriminator must be adjusted. The DISCR is turned counterclockwise until there is no meter indication. Any change in the DISCR control setting may change calibration of the instrument; therefore, calibration must be checked after this readjustment is accomplished.

BETA-GAMMA DETECTION INSTRUMENTS FOR LOW LEVELS OF RADIOACTIVITY

Beta-gamma radiation is usually detected by Geiger-Müeller (GM) counters, ion-chambers, or scintillators. The GM meter is an acceptable instrument for the measurement of low levels of radioactivity and radioactive contamination.

Geiger-Müeller detectors are not without their limitations. GM meters designed for use in detecting low levels of radioactivity (< 50 mR/hr levels) will saturate and remain pegged at the high end of the scale or will drop to zero when exposed to high-intensity radiation fields of approximately 10 R/hr. In either case, the instrument is deemed worthless under these conditions and could give the monitor a false sense of security when a zero reading is indicated; therefore, conduction of a radiation survey in an accident area always should be performed with an ion-chamber backup instrument.

The Eberline Model E-120 Geiger Counter is a portable, lightweight, and compact instrument that utilizes Geiger-Müeller tubes for the detection of beta-gamma radiations (Figure 18-3-4). This instrument can be equipped with either a thin-walled or an end-window GM detector probe. Either of which is adequate and acceptable for the conduction of radioactive contamination surveys.

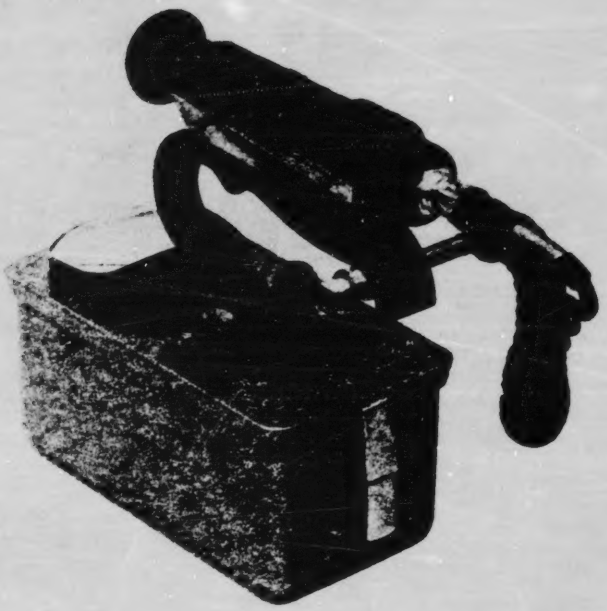


Figure 18-3-4. The Eberline Model E-120 Geiger Counter.

Two "D" size batteries power the instrument, and special circuitry is incorporated to conserve battery life. The battery condition may be checked by a front panel control. The radiation intensity is read out on a large, easily read meter that has a linear scale. Three switch-selected ranges give full-scale sensitivities of 0.5, 5, and 50 mR/hr. The meter response time is continuously adjustable, and the reading may be brought to zero at any time by the reset control. (Sensitivities of 500, 5K, and 50K cpm are available on the Model E-120E.)

A phone output is provided for the use of an earphone, an external speaker, or a scaler (with which events are counted).

Table 18-3-6 contains a description of (1) controls and connectors, (2) operation, and (3) calibration.

TABLE 18-3-6. CONTROLS, USE, AND CALIBRATION OF MODEL E-120 GEIGER COUNTER.

DESCRIPTION OF CONTROLS AND CONNECTORS

1. External (See Figure 18-3-5).
    - a. Switch: Five-position rotary switch that turns instrument OFF, checks battery condition, and selects scale multipliers of X0.1, X1, or X10. This number must be multiplied by the meter reading to obtain the proper field intensity.
    - b. Response: Controls response time of meter to the most desirable compromise between speed and fluctuation for the particular usage.
    - c. Reset: Discharges integrating capacitor, rapidly bringing meter reading to zero.
    - d. Phone: Pulse output for use with earphone, speaker, or external scaler.
    - e. Probe: Connection to hand probe. BNC series coxial.
2. Internal (See Figure 18-3-5).
   Calibration Controls: One control for each range individually calibrates that range to agree with the radiation field.

USE OF THE INSTRUMENT

1. Starting: Turn the switch to the battery check position. The meter should indicate within the BATT OK area.
2. Operation Check: Place the check source in a repeatable position adjacent to the detector, and move the switch to a range that gives an upscale reading. Note that the reading is sensitive to the position of the source. The reading may be recorded for future reference.

   When the RESET button is pushed, the reading should drop to zero rapidly and then climb back to source reading when the RESET is released. The RESPONSE may be adjusted to obtain the most desirable compromise between speed of response and meter fluctuation.
3. Interpretation of Indications: The meter reading must be multiplied by the scale factor to obtain the proper number. The fluctuation of the meter is normal and is caused by the random nature of radioactive decay.

CALIBRATION

For maximum accuracy, the instrument should be calibrated under the same conditions as it will be used.

1. Each range is calibrated individually by a calibration control (X0.1, X1, or X10). Repeat the following procedure for each range.
2. Position the instrument on a calibration range in such a manner that the detector center is

in a field corresponding to near 3/4 scale meter reading.

3. Expose the gamma source, and note the instrument reading. Adjust the calibration control for the range selected until the meter indication agrees with the radiation intensity.

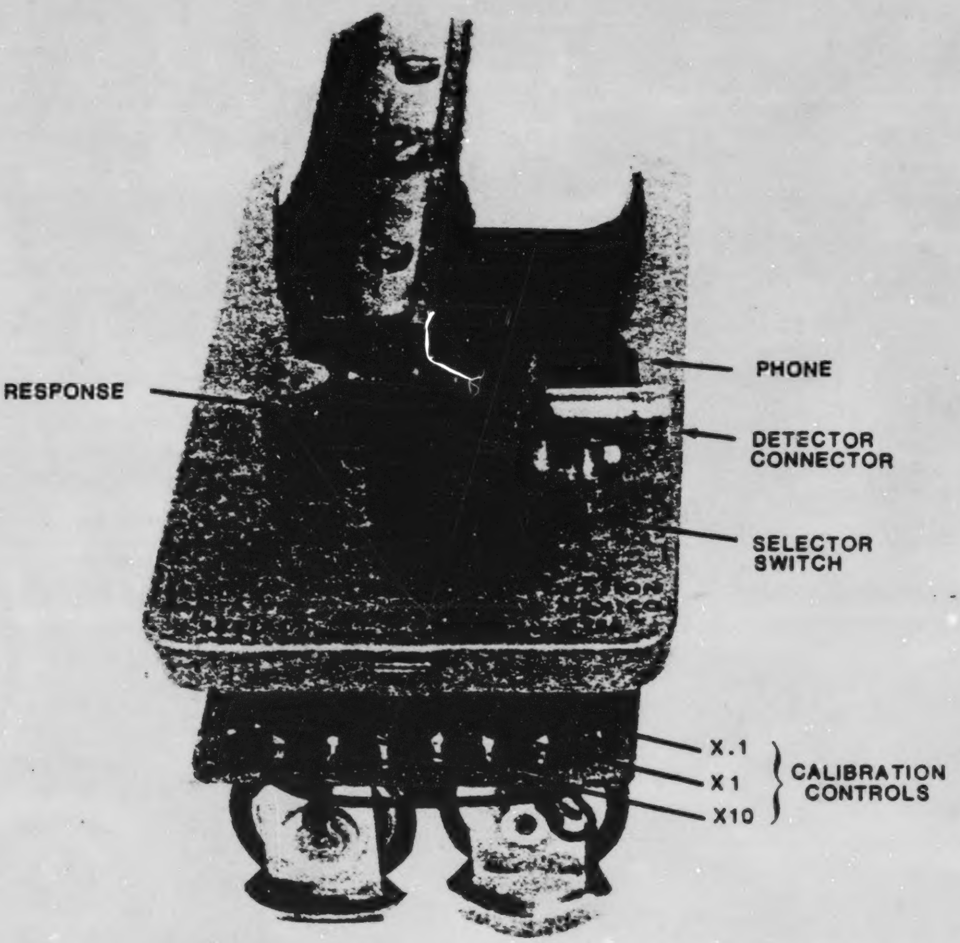

RESPONSE
PHONE
DETECTOR CONNECTOR
SELECTOR SWITCH
X.1
X1
X10
CALIBRATION CONTROLS

Figure 18-3-5. Model E-120 external and internal controls.

DECONTAMINATION

The purpose of decontamination is to remove radioactive material and, thus, to control the levels of radioactivity that could be inhaled, ingested, or absorbed through the skin. Decontamination also is performed to remove and control radioactive materials that present external radiation hazards.

The organization responsible for the radioactive material involved in the accident will be responsible for decontamination efforts and for health protection precautions taken by those persons performing the decontamination.

Radioactive contamination cannot be destroyed, but it can be reloacted or minimized. Decontamination is the transfer, fixing, or decay of these contaminants to allow reuse of the area and equipment and to reduce the health hazard. Decontamination methods vary, depending upon the amount and type of contamination involved. Normally, short half-life emitters are handled through radioactive decay, and the longer half-life emitters are physically fixed or removed.

GENERAL METHODS OF DECONTAMINATION

All personnel should be monitored before leaving the contaminated area. If facilities are available, all personnel should take soap-and-water showers, even when monitoring indicates no skin contamination.

To prevent the spread of contamination to clean areas, all equipment and materials should be decontaminated to permissible levels before being released from the contaminated area.

Scrap metal, wood, equipment damaged beyond repair, and other debris should be considered as waste material and should be disposed of in a suitable manner. Contaminated waste requires special and careful handling to prevent accidental personnel exposure and possible spread of the contamination.

When clothing, tools, equipment, and other usable materials are contaminated, they should be considered waste when time and effort spent in decontamination efforts would exceed their value. The probable success or failure of decontamination methods and the emergency nature of the situation are other factors that determine whether or not usable materials are waste.

Fixed Contamination

Radioactive emitters that cannot be removed easily are fixed contamination. Loose contamination usually is of greater concern than fixed contamination since the possibility of internal deposition is greater.

Removable Contamination

Materials contaminated with removable radioactive contamination are considered as both internally and externally hazardous, but usually are easier to decontaminate.

Material with removable contamination should be packaged or treated to fix the contamination before it is transported to a burial site in order to control the spread of contamination. All such material should be buried in an approved and operationally controlled location. Material with fixed contamination may be transported without special packaging and deposited in an isolated waste-storage location, provided the area is adequately controlled and posted with radiation warning signs. Complete burial eventually is necessary, however, in order to provide additional safety factors.

Water contaminated with low-level radioactive materials may be released to the soil and surface water in accordance with regulatory limits. Water contaminated with high levels of radioactive materials may be transferred to approved burial grounds in accorance with regulations or, in the case of short-lived materials, stored for decay.

Decontamination efforts should be initiated at the lowest area of contamination and progressed to the highest area of contamination. Recovered material should be placed in containers that can be sealed. Salvageable material can be decontaminated by use of numerous agents and methods (Table 18-3-7).

TABLE 18-3-7. DECONTAMINATION AGENTS AND METHODS.

Tape patches	Organic solvents
Vacuum cleaning	Inorganic acids*
Water	Acid mixtures*
Detergents	Caustics*
Steam	Sandblasting*
Ultrasonic vibrations	Abrasions*
Complexing agents	Electrolysis*

*Not to be used on materials with critical dimensions.

Personnel Decontamination

Before personnel can be decontaminated properly, the areas of contamination must be defined by means of proper monitoring techniques. Special emphasis should be placed upon the location of any hot spots on the individual. The mildest methods of cleansing should be attempted first, progressing to more harsh methods when necessary. Care should be exercised in the use of agents stronger than soap and water, as the integrity of the natural skin protection may be jeopardized, resulting in an increased personnel hazard. Cleansing methods in order of harshness are as follows (beginning with the mildest):

- Soap and warm water.
- Mild abrasive soap.
- Complexing solution.
- Mild organic acid.

After removal of contamination, individual should take a thorough shower, washing the hair, hands, and fingernails with special care.

In all personnel decontamination procedures, every effort should be made to prevent the spread of contamination.

Land Area Decontamination

Removal and fixation are two principal methods that can be employed for the decontamination of large land areas:

- Removal. If future use of the area is necessary, contaminated debris may be transferred to an approved burial ground in accordance with regulations. The area is sprinkled with water to prevent airborne resuspension. Next, the top soil of the contaminated earth is removed by blading and scraping to a depth of approximately two to six inches. Finally, the contaminated earth is removed to an approved and operationally controlled burial site.
- Fixation. This method is utilized in areas in which limited future use is anticipated. The area first is sprinkled with water to reduce resuspension of the contaminant. The contaminated top soil then is graded into rows having triangular cross sections; these mounds of earth normally are referred to as "windrows." The windrows are sprayed with hot road oil to fix the contaminant in place and to prevent erosion.

Removal of loose contamination on large, hard-surfaced areas such as roads, parking lots, etc., usually is accomplished by washing of the surface with water under pressure. When the surface is well watered, a mechanical broom can sweep the wash water off the surface and scrub contaminated material out of any crevices. Normally, a rinse with a high-pressure fire hose will complete the removal of the loose contaminant. In some cases, only the first wash is necessary; in other cases, the entire scrub-rinse cycle may have to be repeated several times. Control of the run-off on the side of the road must be accomplished either by removal or by fixation.

Fixation techniques can be classified into four categories as follows:

- Flooding (85% efficient). This technique leaches the contaminant into the surface.
- Oiling (89% efficient). A rapid-cure oil is spread over the contaminated surface.
- Plowing (98% efficient). The land is plowed to a depth of 12 inches to mix and bury the contaminant.
- Paving (100% efficient). The surface is paved with asphalt or concrete to seal the contaminant permanently.

Table 18-3-8 indicates the type of equipment that can be utilized to perform decontamination of large land areas as previously described.

TABLE 18-3-8. EQUIPMENT AND DECONTAMINATION OF LARGE LAND AREAS.

A water tank truck.
A tractor equipped with a revolving cylindrical steel-bristled brush for street sweeping.
A rotary-action, wet-down street sweeper and sweepings collector.
A street brush and vacuum-cleaner machine.
A water-tank truck equipped with a pump, pressure hose, and sprinkling system.

A road-oil tank truck.
A bulldozer.
A road grader.
A flat-rack truck.
A boom truck.
Earth movers.

Decontamination Under Cold Weather Conditions

The use of water as a decontaminating agent depends upon the ambient temperature. As the ambient temperature approaches the freezing point for water, decontamination methods become completely ineffective because of the formation of ice. More effective measures would be realized by the dry sweeping or vacuum cleaning of hard surfaces. If large-area, hard-packed surfaces are to be decontaminated, commercial street sweepers may prove effective.

If contaminated surfaces are covered with light snow, decontamination best is accomplished by sweeping with hand brooms or by a commercial street sweeper, depending upon the size of the area to be decontaminated. It is desirable to sweep the material into windrows and to employ commerical hauling equipment for removal.

Large areas covered with deep snow usually are decontaminated by snow collection and removal with commercial snow plows, road graders, or bulldozers and mechanized truck-loading machines.

The most difficult area of decontamination in cold weather is that encountered when the contamination is frozen in ice. In this case, the ice either must be removed or melted.

The most desirable objective for decontamination would be to remove all possible traces of contaminants; however, this may not be realistic in any sense of practicality. The nature and purpose of all decontamination methods and procedures must be understood because decontamination can be accomplished adequately with the proper methods, regardless of the nature of the incident.

CONTAMINATION LIMITS

The maximum allowed radioactivity remaining on the site after a radioactive contamination incident is determined by the responsible regulatory agency. These limits vary, depending upon several variables that must be evaluated, e.g., is the equipment or site to be returned to unrestricted use? or is there a sufficient quantity of radioactive materials present to endanger the health and safety of the public? These and other variables must be evaluated before an acceptable limit is reached for a specific radiological accident that results in contamination. In general, maximum acceptable surface contamination levels for alpha radiations of an unknown radionuclide origin have been established at 220 dpm/100 cm^2. Maximum levels for beta-gamma radiations are 2200 dpm/100 cm^2. These levels are stated in general terms, and the responsible regulatory agency may amend these limits following their evaluation of the hazards associated with the contamination incident. An example of these amended limits is presented in Table 18-3-9 as those limits acceptable to the U.S. Nuclear Regulatory Commission for the termination of operating licenses for nuclear reactors.

TABLE 18-3-9. ACCEPTABLE SURFACE CONTAMINATION LEVELS (ADAPTED FROM NRC GUIDE 1.86).

NUCLIDE[a]	AVERAGE[b,c]	MAXIMUM[b,d]	REMOVABLE[b,c]
U-nat., ^{235}U, ^{238}U and associated decay products	5000 dpm α/ 100 cm^2	15,000 dpm α/ 100 cm^2	1000 dpm α/100 cm^2
Transuranics, ^{226}Ra, ^{228}Ra, ^{230}Th, ^{228}Th, ^{231}Pa, ^{227}Ac, ^{125}I, ^{129}I	100 dpm/ 100 cm^2	300 dpm/ 100 cm^2	20 dpm/100 cm^2
Th-nat., ^{232}Th, ^{90}Sr, ^{223}Ra, ^{224}Ra, ^{232}U, ^{126}I, ^{131}I, ^{133}I	1000 dpm/ 100 cm^2	3000 dpm/ 100 cm^2	200 dpm/100 cm^2
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except ^{90}Sr and others noted above.	5000 dpm $\beta\gamma$/ 100 cm^2	15,000 dpm $\beta\gamma$/ 100 cm^2	1000 dpm $\beta\gamma$/ 100 cm^2

[a] Where surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides should apply independently.

[b] As used in this table, dpm (disintengrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

[c] Measurements of average contaminant should not be averaged over more than 1 square meter. For objects of less surface area, the average should be derived for each such object.

[d] The maximum contamination level applies to an area of not more than 100 cm^2.

[e] The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.

THE HOT LINE

Removal of radioactive clothing and respiratory equipment takes place at an area designated as the "hot line." The hot line is set up adjacent to the contaminated area for the purpose of controlling the spread of radioactive contamination. Its relationship to other areas involved in the emergency is indicated by Figure 18-3-6.

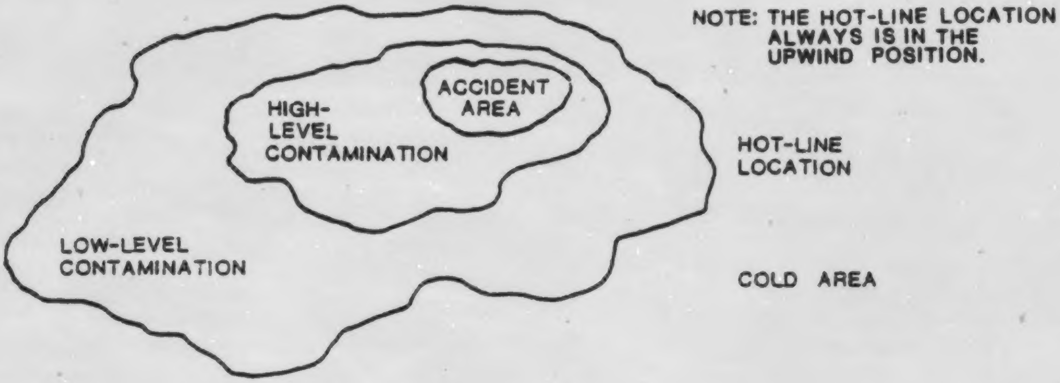

NOTE: THE HOT-LINE LOCATION ALWAYS IS IN THE UPWIND POSITION.
ACCIDENT AREA
HIGH-LEVEL CONTAMINATION
HOT-LINE LOCATION
LOW-LEVEL CONTAMINATION
COLD AREA

Figure 18-3-6. Location of the hot line.

Designation of the areas shown in Figure 18-3-6 should be one of the initial steps in emergency control. The most satisfactory method is to use rope boundaries. If this equipment is unavailable, a doorway entrance or row of flares can be used. An imaginary line can be used as long as everyone understands where it is. One or more persons should be positioned as monitors at the hot line and equipped with instruments with which to perform personnel monitoring of people leaving the hot zone. The monitors should have plastic bags and tape for use in discarding contaminated clothing and radioactive waste and for bagging up contaminated instruments to be decontaminated later.

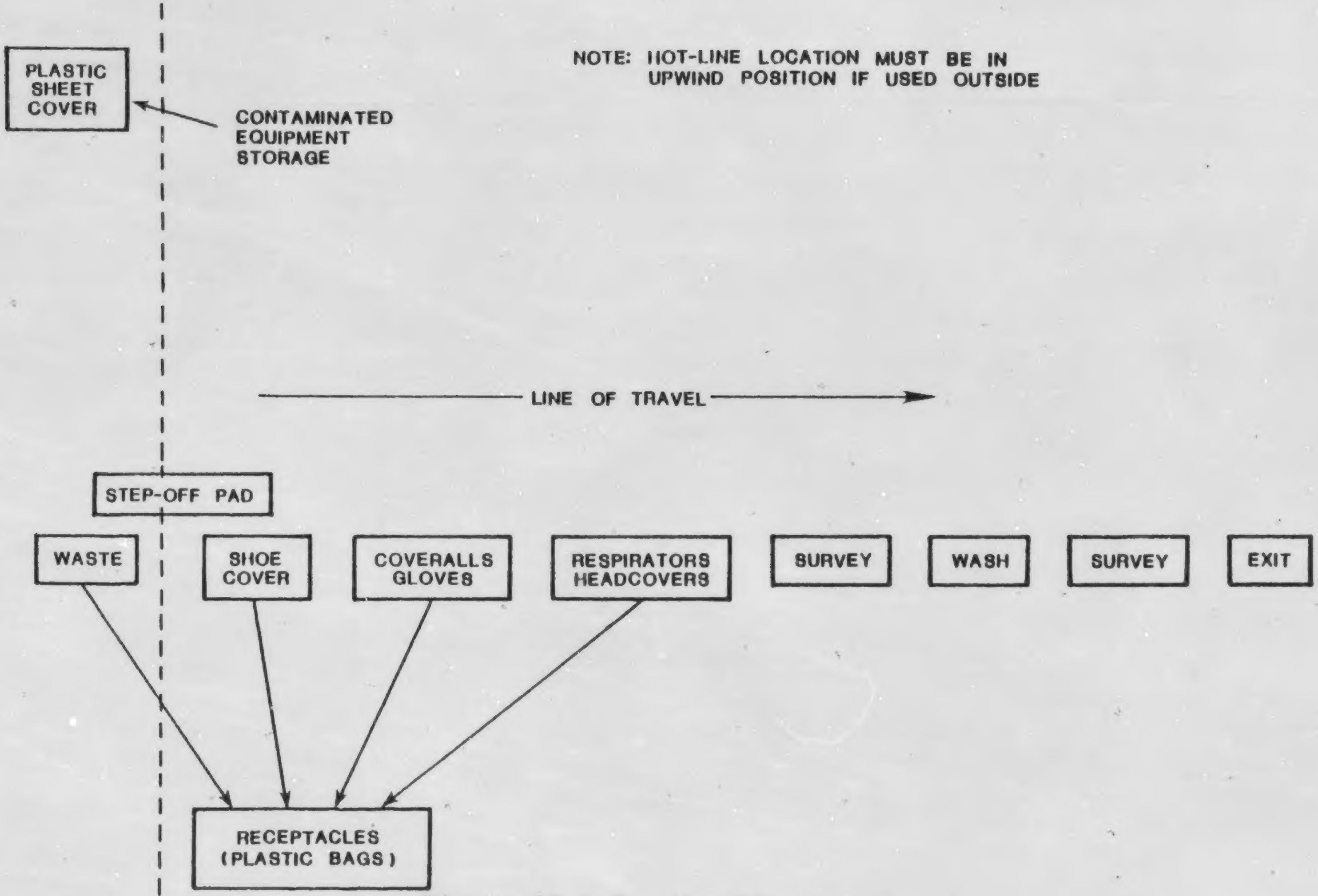
People and/or equipment are not allowed to cross the hot line until free of contamination; this is a prime rule. Proper removal of anti-contamination clothing and respiratory equipment is essential for their overall effectiveness. Instruments or equipment should be placed on paper or plastic sheeting on the contaminated side of the hot line. Removal of protective clothing should be according to the procedures listed in Table 18-3-10.

TABLE 18-3-10. STEP-BY-STEP REMOVAL OF PROTECTIVE CLOTHING.

Step	Procedure
1.	Remove tape and place in bag.
2.	Remove hood and place in bag.
3.	Remove coveralls and place in bag.
4.	Remove one shoe cover, place in bag, and place foot over hot line on cold side.
5.	Remove remaining shoe cover, and step over hot line.
6.	Remove respirator (and surgeon's cap) and place in bag.
7.	Slip off gloves without touching the outside surface, and place in bag.
8.	Be monitored for contamination.
9.	Wash up.
10.	Be monitored again if contamination was found previously (in Step 8).

If two layers of anti-contamination apparel were used, the entire outer layer should be removed (in this case, starting with glove) before moving on to the inner layer of clothing.

The organization of the hot-line equipment should be arranged in such a manner as to facilitate timely and orderly exits from a contaminated area. Proper placement of equipment will establish the line of travel for exit in a predetermined route that will aid in preventing spread of contamination to the cold areas. All personnel and equipment leaving the contaminated area are directed through the hot-line check point. No personnel or equipment will be allowed to pass into the clean (cold) area until they have been surveyed and decontaminated, if necessary. The hot-line check point equipment may be arranged as illustrated in Figure 18-3-7.


PLASTIC SHEET COVER
CONTAMINATED EQUIPMENT STORAGE
LINE OF TRAVEL
STEP-OFF PAD
WASTE
SHOE COVER
COVERALLS GLOVES
RESPIRATORS HEADCOVERS
SURVEY
WASH
SURVEY
EXIT
RECEPTACLES (PLASTIC BAGS)

NOTE: HOT-LINE LOCATION MUST BE IN UPWIND POSITION IF USED OUTSIDE

Figure 18-3-7. Hot-line setup.

EXERCISES

1. Describe how internal radiation hazards can be controlled.
2. Explain how the spread of contamination can be controlled.
3. Explain why both an instrument survey and a smear survey are required.
4. Discuss in a few paragraphs how a hot line is set up for the decontamination of a building such as a laboratory.

MATERIALS

A radiochemistry laboratory or other suitable laboratory that might be isolated for a minimum of 24 hours.

Approximately 100 to 150 μCi of a short-lived isotope; e.g., ^{56}Mn ($T_{\frac{1}{2}}$ = 2.5 hours) for distribution as a contaminant. This isotope can be produced easily in a small research reactor, if one is available. The contaminant should be in solution (liquid form) to prevent airborne radioactivities.

Laboratory scaler/counter for beta counting the smears.

End-window GM survey meters.

Smear paper.

Floor plans of contaminated laboratory.

Sample-counting data sheets.

Protective clothing and equipment: coveralls, shoe covers, disposable gloves, plastic bags, etc., as required.

IDENTIFICATION AND CONTROL OF RADIOACTIVE CONTAMINATION

The objectives of this procedure are as follows:

- To provide the student with continued experience in the use of portable survey instruments.
- To develop in the student the need to define and to document a contaminated area.
- To familiarize the student with techniques and procedures that will assist in preventing the spread of contamination.
- To provide the student with additional experience in the collection and analysis of smear samples.

Steps 1 - 15 must be performed only by the instructor; Steps 16 - 25 involve class participation. The student should read all steps, however, in order that the entire procedure will be clear.

INSTRUCTOR'S TASKS

1. Secure a radiochemistry laboratory or other suitable laboratory that may be isolated for a minimum of 24 hours.
2. Set up a hot-line check point adjacent to the lab entrance; include step-off pads and a survey check station. (Refer to Figure 18-3-7.)
3. Contaminate the lab with ^{56}Mn approximately one hour before class begins.
4. At the beginning of class, briefly review the class objective.
5. Assign students into survey teams #1, #2, #2, ... (2 members per team).

6. Distribute floor plans and counting sheets.
7. Inform the class that the lab is contaminated with ^{56}Mn and that no airborne problem exists.
8. Demonstrate the proper techniques of an end-window GM survey meter for detection of low-level radioactivity.
9. Explain use of battery check and range selection.
10. Readings may be taken in cpm or mR/hr – to be determined by levels of detected radiations.
11. Demonstrate the proper method of preparing smear samples for counting; including use of planchets, loading of holders, and disposal of samples.
12. Explain and demonstrate the proper use of the survey check station.
13. Have demonstration (and student participation) in the proper techniques in the removal of contaminated shoe covers, gloves, etc.
14. Explain controlled use of hands to prevent personal contamination.
15. Explain why an instrument survey must be conducted first. (Data from the instrument survey is used to determine smear survey in order to reflect a composite survey of the lab.)

CLASS PROCEDURES (UNDER STRICT INSTRUCTOR SUPERVISION)

16. Dress for entry into contaminated area, and have instructor check clothing before entry.
17. Survey teams #1 and #2 must enter the contaminated area with all equipment required for the performance of instrument and smear surveys. Each team records instrument readings at different localities and collects

a corresponding smear sample from each area.

18. As teams #1 and #2 perform surveys, the other teams should observe, if possible, the participating teams for both good points and mistakes.
19. Continue survey until all teams have performed both instrument and smear survey.
20. Following completion of surveys, the instructor will demonstrate the proper method of packaging radioactive materials (shoe covers, waste, etc.) to control the spread of contamination.
21. Lock the lab, and mark properly with appropriate radiation warning signs.
22. Survey hot line, and check station area for the spread of contamination to control areas.
23. In the counting room, count the beta activity in each smear sample with the scaler/counter. WARNING: Avoid contaminating self, the equipment, or other collected samples.
24. Compare instrument readings (taken in contaminated area) and sample activity with the same data collected by all other teams. IMPORTANT: This lab should reflect to the student how easily contamination can be spread because the lab should have become more evenly contaminated with each conducted survey. It also is entirely possible that some activity may have been completely removed by some teams during foot traffic and the collection of smear samples.
25. Under instructor's guidance, conduct class discussion about this procedure, including (1) all data taken during the survey, and (2) control of the spread of contamination.

DATA TABLE

None.

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REFERENCE MATERIALS

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Fitzgerald, J.J. Applied Radiation Protection and Control, Volume 2. New York: Gordon and Breach, 1970.

Radiological Emergency Operations. Washington, D.C.: United States Atomic Energy Commission.

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TEST

1. What is radioactive contamination?

2. Identify types of radiations present in contamination.

3. Describe the health hazards of each type of radiation associated with radioactive contamination.

4. What is decontamination?

5. Describe three methods of decontamination.

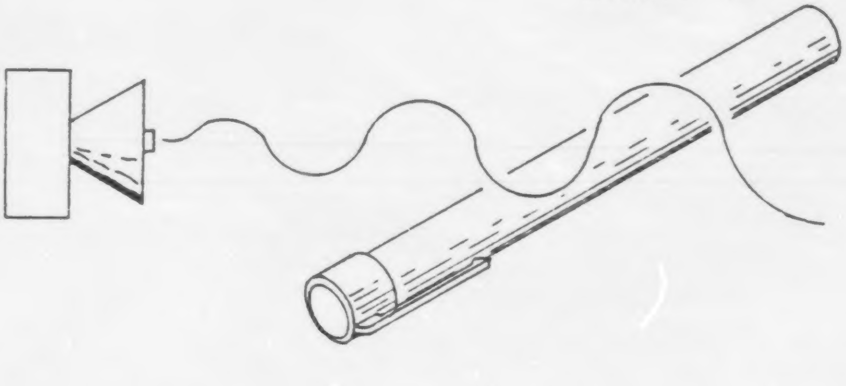
NUCLEAR TECHNOLOGY

MODULE 18-4

CRITICALITY CONTROL

RADIOLOGICAL
EMERGENCIES

COURSE 18



CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

COURSE 18 RADIOLOGICAL EMERGENCIES

Module 18-1	General Procedure for Radiological Emergencies
Module 18-2	Emergency Equipment for Nuclear Facilities
Module 18-3	Surface Contamination – Decontamination
⇨ Module 18-4	Criticality Control
Module 18-5	Control of Radiological Hazards
Module 18-6	Emergency Planning for Nuclear Facilities
Module 18-7	Emergency Drills for Nuclear Facilities

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INTRODUCTION

Operations which involve the processing, storage, or transportation of fissile materials introduce, in addition to other potential radiation risks, the possibility of a criticality accident. A criticality accident is the sudden release of energy as a result of the accidental production of a self-sustaining or diverging neutron chain reaction. Although large quantities of such material have accrued during the development of nuclear energy, there have been only a few cases of uncontrolled nuclear reactions. If this excellent safety record is to be maintained, established safe operating practices must be followed. In the event an accident does occur, proper emergency procedures can effectively limit its consequences.

This module examines the circumstances surrounding accidental criticality and the methods for avoiding it. The proper handling of such emergencies is included in the discussion.

MODULE PREREQUISITES

The student should have completed Course 1, "Radiation Physics"; Course 2, "Radiation Protection I"; Course 5, "Introduction to Nuclear Systems"; Course 11, "Radiation Detection and Measurement"; and Course 17, "Radiation Protection II." The student should be familiar with the basics of nuclear reactions.

OBJECTIVES

Upon completion of this module the student should be able to:

1. Define the following terms:
    - Criticality accident.
    - Multiplication factor.
    - Critical mass.
    - Prompt critical.
    - Single parameter limit.
    - Lattice.
    - Double contingency principle.
    - Double batching.
    - Bird cage.
    - Triage.
    - Fission spike.
2. Discuss the theoretical aspects and general conditions necessary for criticality, and calculate subcritical multiplication (given k_{eff} or the converse).
3. Explain the reasons for a nuclear excursion.
4. Describe the general methods by which criticality can be avoided, and list the minimum critical masses for three fissile isotopes in solution and solid form.
5. Determine four limiting parameters for uranium-water lattices (given enrichment).
6. Discuss safety equipment necessary at facilities that handle fissile materials.
7. Describe administrative practices essential for criticality safety.
8. Sketch a curve of fission rate during a criticality accident, and describe ways for its termination.

9. Explain methods for accident dosimetry, and calculate neutron and gamma doses (given the number of fissions and distance).

10. Outline the proper initial emergency response to a criticality accident.

FISSILE AND FISSIONABLE MATERIAL

Nuclear fission occurs only with certain nuclei of high atomic (and mass) number. When a nucleus absorbs a free neutron, an excited nucleus is formed, and this quickly breaks up into two lighter fission products.

Only three nuclides, which have sufficient stability to permit storage for any significant amount of time, undergo fission by free neutrons of very low or zero energy. These three nuclides are known as "fissile nuclides"; they are ^{235}U, ^{233}U, and ^{239}Pu. Other isotopes also may fission when the incident neutron exhibits a sufficiently high energy ($> \sim$1MeV). These isotopes are ^{238}U and ^{232}Th, which are called "fissionable nuclides." Perhaps a better term for "fissionable" is "nonfissile" because, unfortunately, the two descriptions often are used interchangeably. In this module, they will be used as defined above. The fissile nuclides are those of concern for criticality.

Each of these materials may be found in a nuclear facility. Nuclear reactor fuel may be enriched uranium, which is uranium that has a higher percentage of ^{235}U than naturally occurring elemental uranium, containing 0.72% ^{235}U and 99.28% ^{238}U. Enrichments range from a few percent to almost pure ^{235}U. Some reactors also use ^{239}Pu or ^{233}U as fuel. These isotopes are man-made and are created when ^{238}U or ^{232}Th absorb a neutron without fissioning.

These materials exist in many physical and chemical forms. Research facilities may use pure metal or powder, and aqueous solutions or slurries commonly are found in processing plants. In order to insure the safety of the public, as well as to protect personnel and equipment, the handling of fissile materials must be done in a manner that precludes accidental criticality and minimizes its consequences should it occur.

THEORETICAL CONSIDERATIONS

In order that the student will understand the methods for prevention and control of accidents, the basic conditions necessary for criticality must be reviewed. The effective multiplication factor, k_{eff}, of a system containing fissile material is defined by —

$$k_{eff} = \frac{\text{Number of neutrons produced by fission in one generation}}{\text{Number of neutrons produced by fission in the preceeding generation}}.$$

If $k_{eff} = 1.00$, the number of neutrons remains the same in each generation, and the rate of fission is constant. In this case, the reactor is said to be critical. Similarly, a decreasing fission rate and neutron population in each generation indicates $k_{eff} < 1$, and the reactor is subcritical. In this case, for every neutron-producing fission, less than one neutron, on the average, returns to continue the process. If an external source of neutrons is present, a steady-state flux level will be reached due to subcritical multiplication of the source neutrons. The subcritical multiplication factor, M, is defined as —

$$M = \frac{\text{Neutron level with source plus fissile material}}{\text{Neutron level with source alone}}.$$

If a source alone yields S thermal neutrons, the number of neutrons produced from fission in the first generation will be $S_1 = S(k_{eff})$. The number in the second generation

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will be $S_1(k_{eff})$, or $S(k_{eff})^2$, and so on. After n generations, a steady-state level of neutrons will be reached. For a constant source strength, there always will be neutrons in each generation. The total present is given by Equation 18-4-1.

$$S_{total} = S + S_1 + S_2 + \dots S_n, \qquad \text{Equation 18-4-1 (Equation = Eq.)}$$

$$\text{or } S_{total} = S + Sk_{eff} + Sk_{eff}^2 + \dots Sk_{eff}^n.$$

This is the steady-state neutron level as long as k_{eff} remains unchanged.

If – Equation 18-4-1 is divided by S, the subcritical multiplication becomes –

$$M = \frac{S_{total}}{S} = 1 + k_{eff} + k_{eff}^2 + \dots k_{eff}^n \qquad \text{Eq. 18-4-2}$$

Mathematically, this relationship is equivalent to Equation 18-4-3.

$$M = \frac{1}{1-k_{eff}} \qquad \text{Eq. 18-4-3}$$

If the source is removed, the neutron level goes to zero. Assuming that nothing is done to increase k_{eff}, the system is stable.

As k_{eff} approaches 1.0 (criticality), the subcritical multiplication approaches infinity. Although this is only a mathematical formulation not valid for $k_{eff} \geq 1.0$, it can be used to predict criticality. Note that –

$$\text{as, } M \rightarrow \infty,$$
$$1/M \rightarrow 0.$$

Thus, if 1/M is plotted as a function of the amount of fissile material and extrapolated to zero, an estimate of the critical fuel mass can be obtained. (See Figure 18-4-1.)

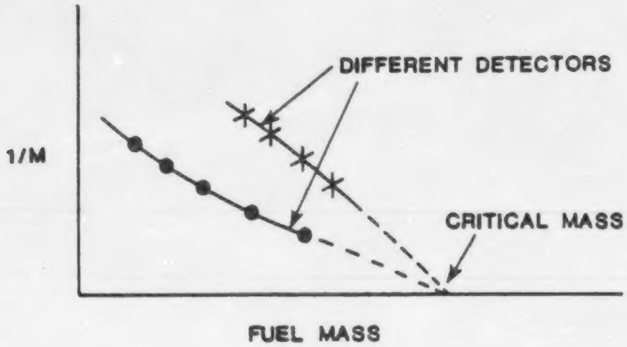

Figure 18-4-1. Prediction of critical mass.

EXAMPLE

Given: During a subcritical multiplication measurement on a new mixing tank, the neutron count rate with the source alone in the tank is 40 counts per second. The tank is slowly filled. With the tank three-fourths full, the count rate is 800 cps.

Find: k_{eff} at this point.

Solution:

$$M = \frac{1}{1-k_{eff}}, \text{ or}$$

$$k_{eff} = \frac{M-1}{M}$$

$$M = \frac{800 \text{ cps}}{40 \text{ cps}} = 20$$

$$k_{eff} = \frac{20-1}{20} = 0.950.$$

If k_{eff} is greater than 1.0, the system is supercritical, and an increase in the fission rate results. Exactly how rapidly the fission rate increases depends upon how much greater k_{eff} is than 1.0. The more the deviation, the faster the increase.

The transient behavior of a supercritical system is the result of a combination of factors. Fission neutrons can be classified as prompt neutrons emitted within 10^{-14} seconds of a fission, and delayed neutrons released sometime later as a result of radioactive decay of fission products. The fraction of neutrons delayed is designated as β. These values are listed in Table 18-4-1. Although they represent only a small fraction of the total fission neutrons, their effect is to prolong greatly the effective neutron lifetime, $\bar{\ell}$, which is the average time elapsed between production of a neutron from fission and its loss by escape or absorption. In a nuclear reactor, for example, this prolonged lifetime allows manual control, which would be impossible with prompt neutrons alone.

TABLE 18-4-1

NUMBER OF FISSION NEUTRONS DELAYED PER FISSION

	^{235}U	^{233}U	^{239}Pu
Total Neutrons Per Fission	2.43	2.50	2.90
Number Delayed	0.0158	0.0065	0.0058
Fraction (β)	0.0065	0.0026	0.0020

If the deviation of k_{eff} from 1.0 is sufficient, the system behaves as if all neutrons were prompt. This condition is known as "prompt critical" and results in a very rapid increase in fission rate. This is the situation in a criticality accident.

To examine this condition a little more closely, consider the prompt neutron lifetime, ℓ_p, which has the same definition as ℓ, but applies only to prompt neutrons. The value of ℓ_p may range from $10^{-3} - 10^{-6}$ seconds, depending upon the amount of fissile material present. Further, the excess multiplication, Δk, is given by Equation 18-4-4.

$$\Delta k = k_{eff} - 1. \qquad \text{Eq. 18-4-4}$$

For prompt criticality,

$$\Delta k \geq \beta.$$

In this situation, the fission rate, F, increases approximately as indicated in Equation 18-4-5.

$$F(t) = F(o)e^{\Delta kt/\ell_p} \qquad \text{Eq. 18-4-5}$$

where:

$F(t)$ = Fission rate after t seconds.
$F(o)$ = Fission rate at $t = o$.
ℓ_p = Prompt neutron lifetime in seconds.
Δk = Excess multiplication.

The following example illustrates the need to avoid prompt criticality when handling fissile materials.

EXAMPLE

Given: An accidental change in multiplication from 1.00 to 1.01. The value of ℓ_p is 10^{-4} seconds.

Find: The factor by which the rate of fission will increase in 0.1 second.

Solution:

$$\frac{F(t)}{F(o)} = e^{0.01(0.1)/10^{-4}}$$

$$= e^{10}$$

$$\frac{F(t)}{F(o)} = 22{,}026.$$

FACTORS THAT AFFECT CRITICALITY

In the design of facilities and procedures with the objective of preventing criticality accidents, a number of variables that relate the shape and dimensions of a mixture of fissionable material to its nuclear properties must be considered. The effective multiplication factor can be expressed in the form of Equation 18-4-6.

$$k_{eff} = k_{\infty} (P) \qquad \text{Eq. 18-4-6}$$

where:

k_{∞} = Infinite multiplication factor.
P = Nonleakage probability.

The infinite multiplication is the k_{eff} of an infinitely large system. The nonleakage probability, P, is defined as –

$$P = \frac{\text{Neutrons absorbed in the system}}{\text{Neutrons absorbed in system + neutrons leaking from system}}$$

P must always be less than 1.00 for a finite assembly.

Although k_{∞} depends upon the properties of the fissile material, P depends upon its geometry as well. Given a particular geometrical arrangement, the minimum mass of fissile material that can be made critical in that configuration is called the "critical mass." There is also a minimum critical mass, which is the smallest critical mass obtainable under ideal shape, moderating, and reflecting conditions. Moderators are media that reduce the energy of fission neutrons through collision in order that continued fission may occur

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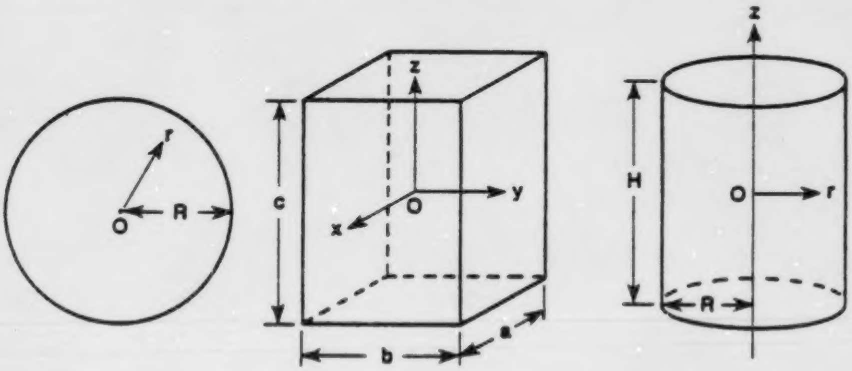
more easily. Typical moderators are water, graphite, D_2O, and beryllium. Reflectors are moderator materials placed around a core of fissile material to reduce neutron leakage.

The surface-to-volume ratio (S/V) of a geometrical shape is an important factor. The lower this ratio, the fewer neutrons that escape. For a given volume, a sphere has the minimum surface area. Three basic geometries are illustrated in Figure 18-4-2 with their optimum dimensions and S/V ratios.



	SPHERE	RECTANGULAR PARALLELEPIPED	FINITE CYLINDER
OPTIMUM DIMENSIONS	R	a = b = c	H = 1.847R
S/V	3/R	6/a	$\frac{3.083}{R}$ OR $\frac{5.694}{H}$

Figure 18-4-2. Optimum geometries for criticality.

Thus, for a given amount or concentration of material, the sphere is the optimum shape. The cylinder is the next most optimum, and the cube is the third. Other shapes require more volume. The actual dimensions required depend upon the amount of material present.

CRITICALITY CONTROL

The classical approach to preventing accidental criticality is to select one variable with which to control in a system of fissile isotopes assuming the other parameters are optimum. This variable is known as the "single parameter limit," but it is used only under specified conditions. Table 18-4-2 lists some of the basic single-parameter limits for homogeneous aqueous solutions and metal that contains no internal moderator. This particular table assumes that a thick hydrogenous reflector such as water is present. In practice, adequate safety margin should be allowed to account for uncertainty in the experiments which led to these values.

TABLE 18-4-2
SINGLE-PARAMETER LIMITS*

Parameter	^{235}U Minimum Critical	^{233}U Minimum Critical	^{239}Pu Minimum Critical
Mass, kg (any vessel; any dimension)			
Aqueous solution	.76	.55	.51
Metal	20.1	6.7	4.9
Diameter of infinite Cylinder, cm.			
Aqueous solution	13.9	11.5	15.7
Metal	7.3	4.6	4.4
Thickness of infinite slab, cm.			
Aqueous solution	4.6	3.0	5.8
Metal	1.30	.54	.65
Volume of spherical Aqueous solution, liters	5.8	3.5	7.7
Chemical concentration of aqueous solution, grams (of isotope)/liter (any vessel, any dimension)	11.5	10.8	7.0

*From ANS-8.1/N 16.1, 1975.

The following two examples demonstrate the use of Table 18-4-2.

EXAMPLE
Given: A ^{235}U metal of optimum shape and a water reflector.
Find: Maximum allowable mass of metal.
Solution: From Table 18-4-2,
Maximum mass = 20.1 kg.

EXAMPLE
Given: A ^{239}Pu aqueous solution.
Find: Maximum allowable concentration of ^{239}Pu.
Solution: From Table 18-4-2,
Maximum concentration = 7.0 grams/liter.

Up to this point, the discussion has been concerned only with pure fissile nuclides. In practice, these are found mixed with fissionable isotopes. The values presented in Table 18-4-2 can be used conservatively for isotopic mixtures, as well. In such a mixture, the enrichment of the isotope also may be used as a single-parameter limit. Natural uranium cannot become critical in homogenous mixtures with water in any proportion. If the uranium is enriched, however, the solution can be made critical. The single-parameter limit for uranium enrichment in an aqueous solution is 1.0%. This is uranium containing 1.0% ^{235}U and 99.0% ^{235}U. Further, a single piece of uranium metal less than 5% enriched cannot become critical in any configuration with a water reflector.

As a rule, the critical mass of a fissile material associated with a moderator is minimal in an intimate mixture such as an aqueous solution; however, uranium that contains a few percent ^{235}U is an exception, with a lower critical mass resulting when it is latticed in a moderator. A lattice is a region that contains a regularly repeating arrangement of material. In this situation, multiparameter control is more appropriate; that is, the simultaneous limitation of two or more parameters. Usually, these are the enrichment plus one of the parameters in Table 18-4-2. Figures 3-6 give the allowable values for some of these parameters as a function of enrichment in uranium-water lattices, assuming water reflection. Immediately following these figures, two examples are provided to illustrate their use.

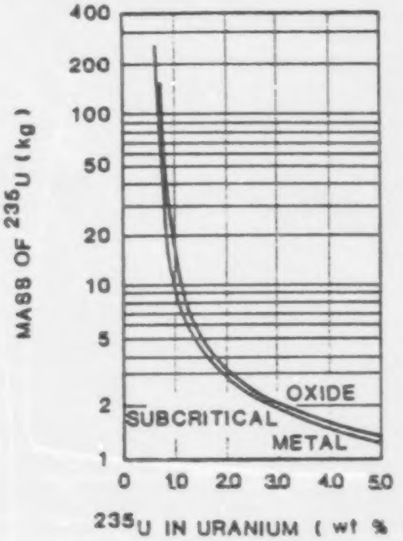


Figure 18-4-3. Mass limit for uranium-water lattices.

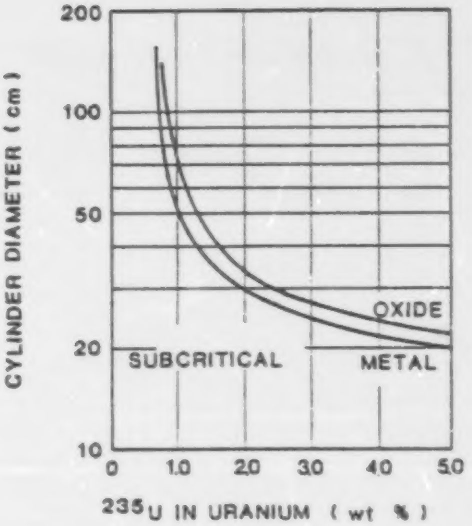


Figure 18-4-4. Cylinder diameter limit for uranium-water lattices.

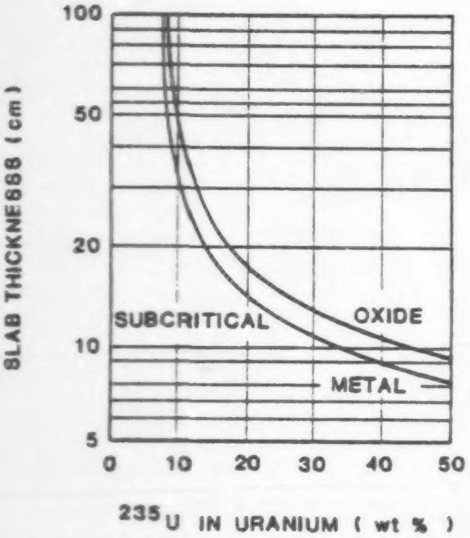


Figure 18-4-5. Slab thickness limit for uranium-water lattices.

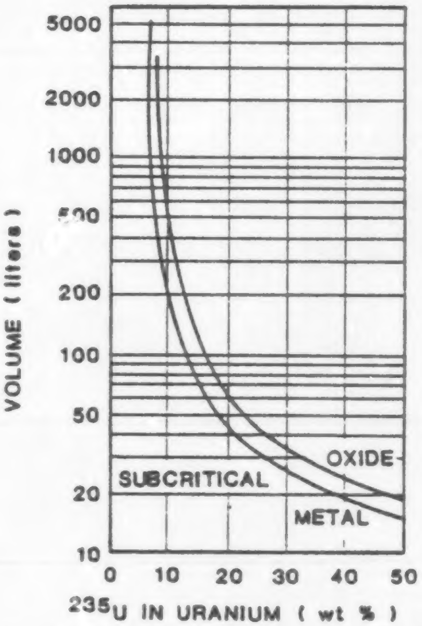


Figure 18-4-6. Volume limit for uranium-water lattices.

EXAMPLE

Given: A water-reflected lattice array of 3% enriched UO_2.

Find: Maximum allowable mass of ^{235}U.

Solution: From Figure 18-4-3,
Maximum mass = 2.1 kg.

EXAMPLE

Given: Any lattice placed in a cylinder 30 cm in diameter.

Find: Maximum allowable enrichment of uranium metal that will prevent criticality.

Solution: From Figure 18-4-4,
Maximum enrichment = 2.0%.

In using the data presented in the preceeding tables and figures, some points must be remembered. The values are based upon measurements and calculations for simple geometries and materials. In complex systems, it is very difficult or impossible to calculate or measure critical masses with any degree of accuracy. For this reason, adequate safety margins must be included in the design of any facility for which possible criticality is a concern. In addition, potentially abnormal circumstances must be analyzed, assuming violations of procedures, equipment failures, etc. As a practical matter, special expertise must be sought on all but the most simplistic cases.

HANDLING AND STORAGE OF FISSILE MATERIALS

In storing fissile materials the limitations presented in the previous discussion can be attained through engineering and administrative controls. These controls will include design features intended to minimize the potential for criticality through restrictions imposed upon the mass, concentration, or size. The double contingency principle states that processes should be designed to incorporate margins of safety in such a manner that at least two unlikely, independent, and concurrent changes in one or more of the specified conditions must occur before a nuclear accident is imminent. An example of this philosophy might be found in a mixing process in which not only must an error be made in the concentration of a solution, but the solution must be placed in the wrong type of vessel.

In practice, such margins are attained by conservative design assumptions; for example, it might be postulated during the sizing of a piping system that flooding had occurred, surrounding the pipes with water. Where materials with uncertain reflective properties are used, a limiting condition should be assumed. Concrete is such a material, and to treat it as pure water is conservative.

Under conditions in which persons remotely manipulate fissile materials behind shielding sufficient to limit their exposure to a safe level in the event of a criticality accident, a single contingency principle is allowable. Table 18-4-3 lists control parameters that may be used in either double- or single-contingency operation. Some of these parameters have been discussed in detail earlier as single- or double-parameter limits.

In the design of storage or processing facilities, the possiblity of double batching must be considered. Double batching is the combination of two unit masses of material intended to be kept separate and thus subcritical. This may or may not result in criticality. For prevention of double batching, such things as limited capacity containers or preventative storage-cell design must be considered. A bird cage is a device whereby a cagelike structure is attached to a storage container to maintain a safe distance between a body of fissile material and other objects such as other fissile bodies or reflecting media. Bird-cage design is illustrated in Figure 18-4-7.

TABLE 18-4-3

CONTROL PARAMETERS

Method of Control	Description
Neutron Absorbers	Maintain a minimum concentration of a soluble or solid neutron absorber (e.g., boron, gadolinium, cadmium etc.).
Concentration	Do not exceed a maximum allowable concentration of fissile material in solution (e.g., grams ^{235}U/liter).
Geometry	Maintain a fixed geometry of material (e.g., cylinder, cube).
Reflectors	Prevent reflector conditions other than those analyzed (e.g., flooding with water).
Enrichment	Do not exceed a maximum enrichment of fissile material (e.g., < 50% ^{235}U).
Chemical Form	Prevent alteration of chemical form that might change physical properties (e.g., precipitation and settling cuased by a change in pH).
Spacing	Keep a minimum lattice spacing between discrete units (e.g., minimum space between stored fuel rods).

There are numerous techniques to implement the control parameters of Table 18-4-3 in materials processing. If chemically allowable, an operation may be carried out with a soluble neutron absorber actually mixed with the process material.

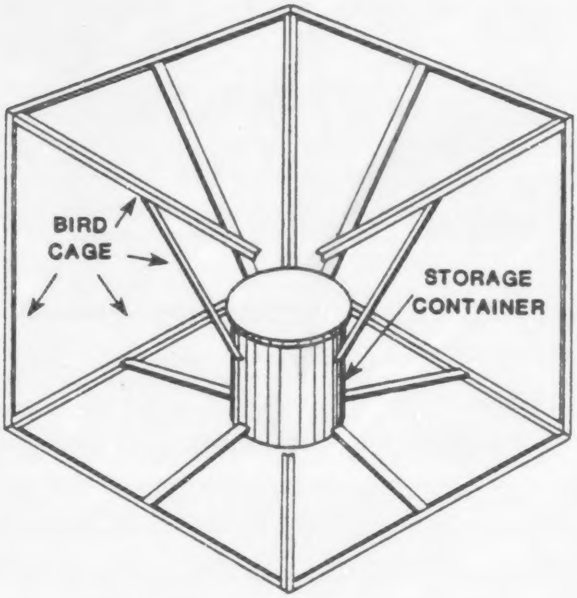
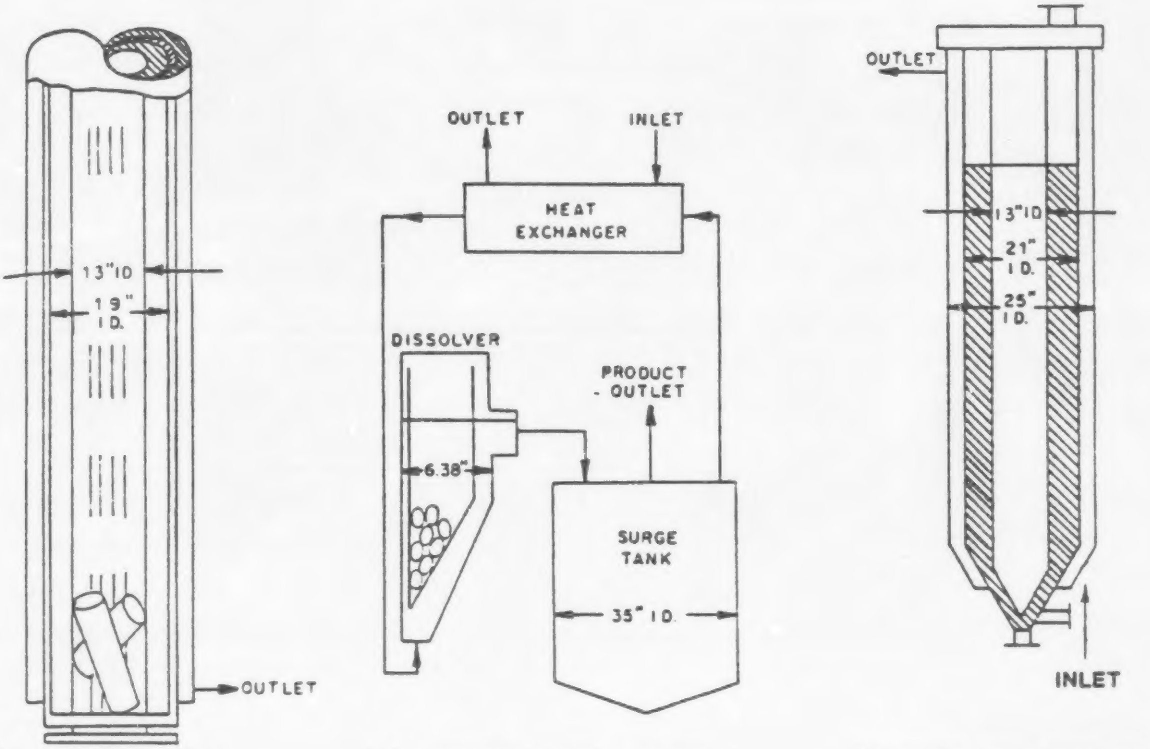


Figure 18-4-7. Typical bird cage and storage container.

Illustrations of equipment employed for this purpose in a fuel reprocessing facility are given in Figure 18-4-8. If the use of such equipment is impossible, an alternative is borosilicate-glass raschig rings. A raschig ring is a small, hollow cylinder having approximately equal length and diameter. The rings are 1 1/2 inches in diameter or less, and allow poison control without chemical interference with the solution. Usually, they are densely packed in the container. Automatic shutoff valves may be utilized to terminate accidental addition of solution. Remote dilution and draining capability must be provided for concentration control. Tank sizes should be the minimum needed, with adequate pressure-containment capability.


13"ID
19"
I.D.
OUTLET
OUTLET
INLET
HEAT
EXCHANGER
DISSOLVER
PRODUCT
- OUTLET
6.38"
SURGE
TANK
35" I.D.
OUTLET
13"ID
21"
I.D.
25"
I.D.
INLET

(a) ZIRCONIUM–ALLOYED FUEL DISSOLVER

(b) STAINLESS STEEL CLAD FUEL DISSOLUTION PROCESS LOOP

(c) ROVER FUEL DISSOLVER

Figure 18-4-8. Equipment that requires criticality control in a fuel reprocessing plant.

In nuclear power plants, concern over accidental criticality is limited primarily to fuel storage. Fuel bundles are stored in a specified area, usually in a storage rack. This may be a dry rack for new fuel or one positioned in a water pool for irradiated fuel bundles that require shielding and cooling. In general, these facilities are designed to limit k_{eff} to $\leq 0.90 - 0.95$ by sufficient lattice spacing and/or the use of neutron absorbers such as boron, cadmium, or gadolinium. Another operation of interest in any nuclear reactor is the measurement of subcritical multiplication for prediction of critical mass (Equation 18-4-2). This experiment must be carefully planned, monitored, and controlled so that a surprise excursion is precluded.

If lattice spacing is utilized as one of the parameters for control, extensive measurements and detailed calculations are necessary to verify the minimum allowable spacing. These values have been published for many sets of conditions; therefore, finding conservative limits for a specific purpose is possible almost always. Presently, however, all storage space is very crucial at nuclear power-plant sites because of the accumulation of spent fuel in the storage pools. This shortage of storage space has resulted in the need for denser packing of storage lattices; therefore, ultra-conservative spacing may be impossible to accept. Storage-rack manufacturers have designed facilities with large amounts of poison to accommodate this situation. In this case, the manufacturer's specified limits are used in order that optimum use of storage space can be achieved. A typical fuel storage rack is shown in Figure 18-4-9.

Potential criticality also may be a concern in the transportation of nuclear material. When fissile material is shipped, prudence suggests the use of a single-parameter limit (Table 18-4-2) with safety margin to ensure a subcritical system even under unforeseen conditions such as a vehicle accident, flooding, double batching, container failure, etc. Shipment usually is not a potential hazard with experimental quantities of materials, but nuclear reactor fuel poses special problems. Reactor fuel rods or bundles are designed specifically for the purpose of creating a critical array under

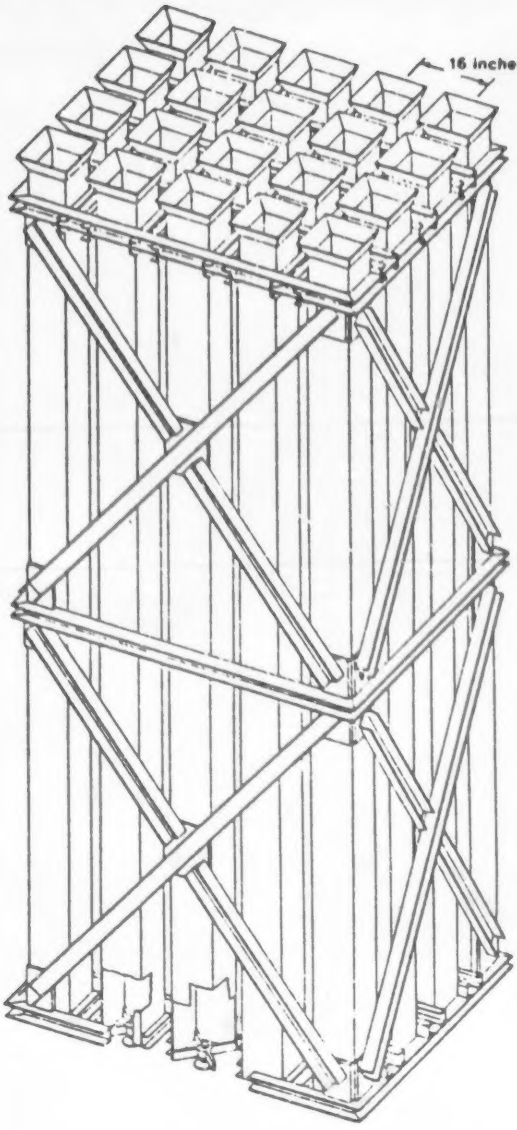


Figure 18-4-9. Fuel storage rack.

the right conditions; therefore, care must be taken to ensure that these conditions are prevented. Unirradiated fuel is shipped in unshielded containers designed to resist damage and is surrounded by a bird cage to prevent unacceptable geometries. Irradiated, "spent" fuel is shipped in heavy casks, such as that in Figure 18-4-10, which provide shielding and cooling. These casks are tested extensively for ability to withstand impact, fire, and immersion in water. Although depleted reactor fuel may be only a few percent enriched and poisoned by fission products, the casks still must contain neutron absorbers for ensurance of safety in all situations. To date, there have been no criticality related accidents in transportation.

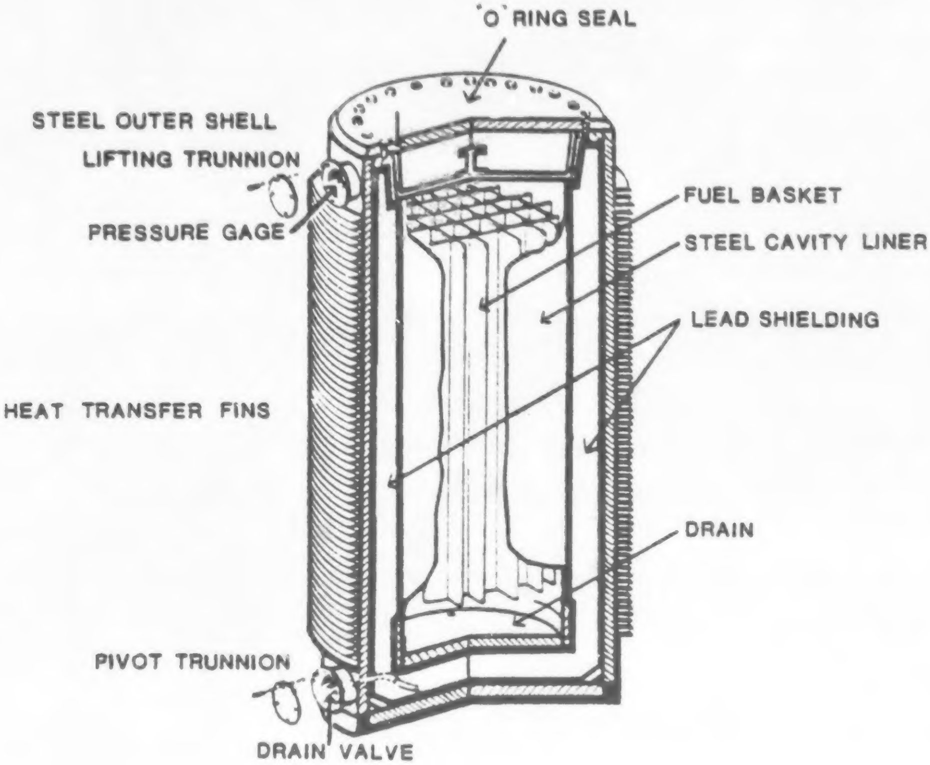

'O' RING SEAL
STEEL OUTER SHELL
LIFTING TRUNNION
PRESSURE GAGE
FUEL BASKET
STEEL CAVITY LINER
LEAD SHIELDING
HEAT TRANSFER FINS
DRAIN
PIVOT TRUNNION
DRAIN VALVE

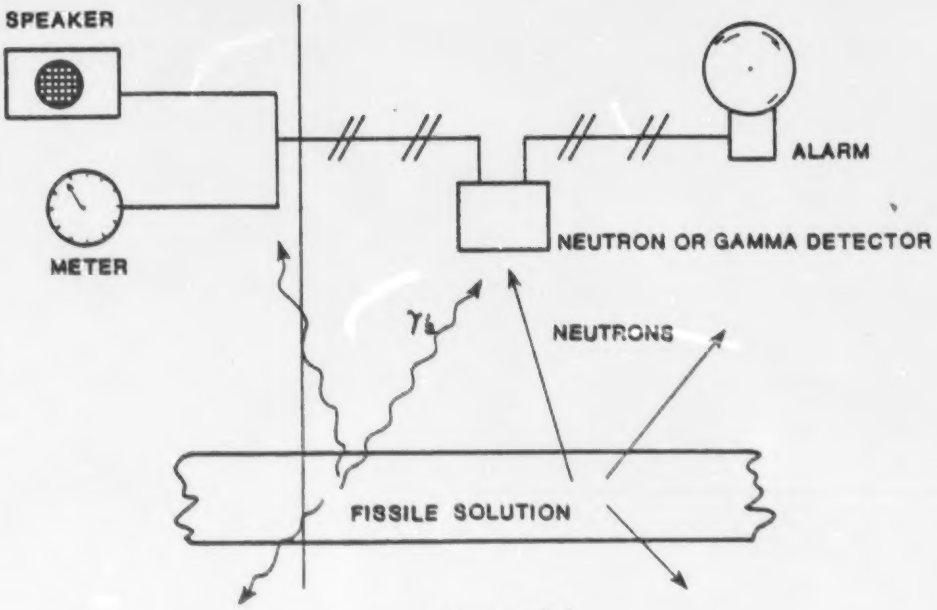
Figure 18-4-10. Spent fuel shipping cask.

SAFETY INSTRUMENTATION

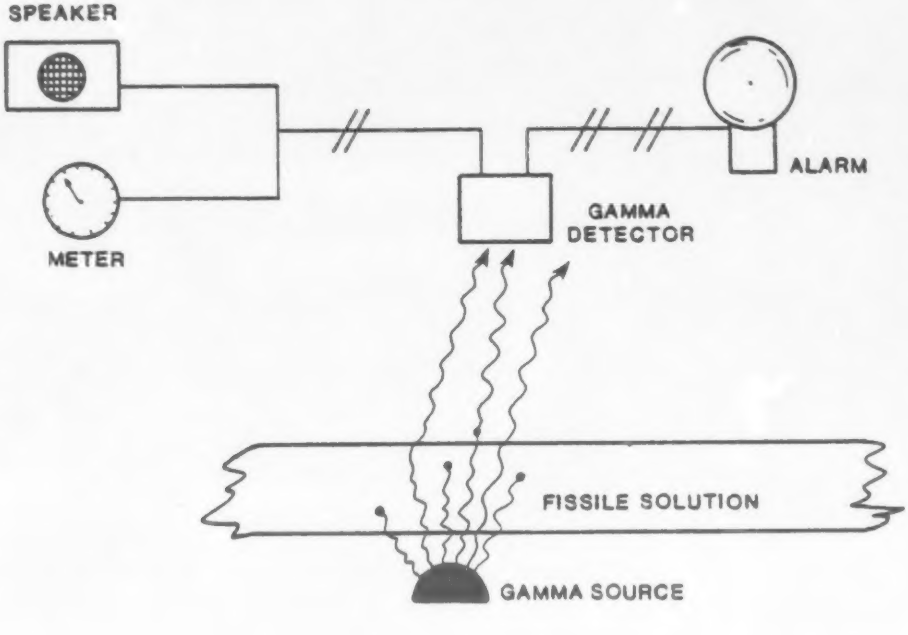
Radiation detection instruments can be used effectively to warning of an impending criticality hazard. Such warning alerts personnel and initiates evacuation procedures. Such a detector system, with its associated output, is called a "criticality accident alarm." According to published guidelines, criticality alarms should be present if there is the potential for an accident that could cause an exposure of 25 rem in 1 minute or less at a distance of 6 feet from the accident.

Criticality alarms should be designed to measure not only the radiation level, but also the rate of increase of this level. They must have a large range for continuous, full-accident monitoring. Remote readout with recording capability is desirable. In order to prevent false alarms, concurrent response of two or more detectors, with trip points set high enough to prevent spurious signals, may be required. There are two basic approaches: (1) direct, in which the prompt radiations of fission are measured; and, (2) indirect, in which properties of fissile/fissionable isotopes, or other closely associated materials in chemical processes, may be utilized.

Figure 18-4-11 illustrates two indirect methods. In Method A, accumulations of ^{235}U or ^{239}Pu are detected by measurement of their characteristic gamma radiation or neutron emissions, respectively. The gammas are emitted in the natural decay chain. Neutrons come from the spontaneous fission of ^{240}Pu, which usually accompanies ^{239}Pu, and their subsequent multiplication. Spontaneous fission is a form of radioactive decay in which, on rare occasions, a nucleus will


SPEAKER
ALARM
METER
NEUTRON OR GAMMA DETECTOR
γs
NEUTRONS
FISSILE SOLUTION

Method "A"


SPEAKER
ALARM
METER
GAMMA DETECTOR
FISSILE SOLUTION
GAMMA SOURCE

Method "B"

Figure 18-4-11. Indirect methods of safety monitoring.

fission by itself with no incident neutron. Method B takes advantage of the absorption by heavy elements of γ-rays directed through a process stream. Both of these provide a means for concentration control.

A multiplication-measuring system may be employed in the direct detection of any significant increase in subcritical multiplication. This system consists of a source of neutrons, preferably distributed in the process material, and of a properly positioned neutron detector. It is best suited for aqueous solutions. (Recall from Equation 18-4-2 that a source of neutrons does not increase k_{eff}; it only provides a steady neutron level with which to measure.)

The most widely used method is the direct measurement of prompt fission gamma radiation with Geiger detectors. Each fission releases several γ-rays, carrying, on the average, ∿ 7 Mev of total energy. Thus, the gamma emission rate is directly proportional to the rate of fission. Table 18-4-4 lists some typical design values for criticality alarms.

TABLE 18-4-4
SPECIFICATIONS FOR CRITICALITY ALARMS*

Design Parameter	Design Value
Transient fissions (total)	1×10^{15} fissions for 1-msec.
Transient sensitivity	1/2500 of actual dose rate or greater
Sustained fission rate	1.74×10^{14} fission/sec for 1 min.
Alarm trip point	50 mR/hr.
Maximum detector spacing	450 feet (less for massive shielding
Coincidence	2 detector activiation
Alarms	Audible with remote resets
Tests	Weekly to monthly

Note the transient sensitivity, which indicates that electronic detectors are not capable of exactly responding to extremely rapid transients. The factor of 1/2500 has been measured and is the basis for the other parameters listed.

*From ANS-8.3/N16.2, 1969.

ADMINISTRATIVE PRACTICES

The ultimate responsibility for criticality control rests with management. Supervision should be provided for nuclear criticality safety as well as for production, research, or other functions. Only those facilities that handle small amounts of material may refer their problems totally to qualified consultants. There actually are no intrinsic differences in criticality control and other types of industrial safety. Listed below are some basic administrative practices that minimize the possibility of accidental criticality:

- Process Analysis. New operations or changes must be analyzed for subcriticality under normal and abnormal conditions. This analysis may include subcritical neutron multiplication measurements.
- Written Procedures. They ensure consistent, safe operational practices.
- Materials Control. Labeling of materials as to type and the posting of all limits on parameters subject to control are essential.
- Operational Control. Deviations from procedures or unforeseen alterations in process conditions must be investigated promptly, and proper action must be taken.
- Operational Reviews. Operations should be reviewed frequently as to adequacy of procedures and adherence thereto. Preferably, the review involves some individuals not directly responsible for the operation.
- Emergency Procedures. Responses to emergencies must be written, and personnel made familiar with them. Responses include evacuation procedures, rescue operations, training and drills, medical arrangements, and interactions with off-site agencies.
- Post Accident Analysis. Methods must be established for the assessment of accident effects. Included are personnel dosimetry, environmental monitoring, and accident diagnostics.

CHARACTERISTICS OF CRITICALITY ACCIDENTS

Even under the double-contingency principle, multiple breakdowns in nuclear criticality controls could lead to an accident. Normally, criticality incidents are characterized by an initial fission spike burst, followed by a rapid, but incomplete, decay. Next may come a plateau period of some length until shutdown is completed. The total fissions generated usually range between $\sim 10^{15}$ and 10^{20} (10^{17} fis = 1 kW-hr), most of which occur in the spike. Of course, the possibilities vary widely with the situation. A typical curve of fission rate versus time is given in Figure 18-4-12. The spike is of particular importance because of its rapid nature, which prevents evacuation during its occurrence. Shielding must be provided, therefore, to protect personnel from the radiations associated with the short-duration spike.

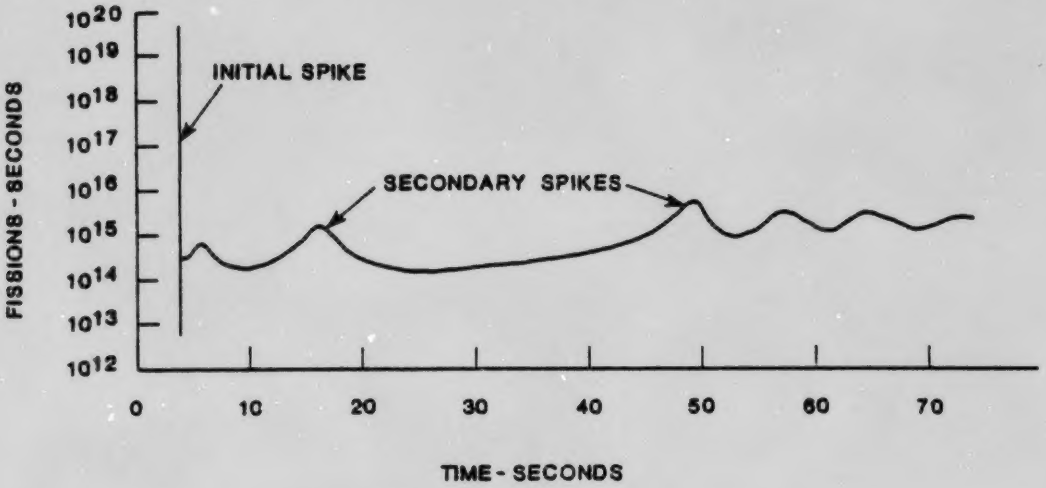


Figure 18-4-12. Fission rate during a criticality accident.

Nuclear excursions may be terminated in a number of ways. The preferable way is through safety mechanisms discussed earlier, although the tendency of a heated, supercritical system to alter its own physical properties may be the final shutdown mechanism. In solutions, the thermal expansion of the liquid and the formation of vapor bubbles sufficiently decrease the density for subcriticality. Subsequent spikes (Figure 18-4-11) may be expected of smaller intensity than the first as the solution cools, as the bubbles collapse, and as criticality again ensues. Mass may be lost through splashing or expansion, and a lower steady-state fission rate will be reached. Many minutes or hours can elapse before final termination.

Although each accident is unique, estimates have been made of the upper limit of the number of fissions occurring in both the spike and the plateau. For solutions of uranium under various supercritical conditions, experimental and past accident data agree reasonably well with Equation 18-4-7.

$$F_s = 2.95 \times 10^{15}(V^{.82}). \qquad \text{Eq. 18-4-7}$$

where:

F_s = total fissions in the spike areas.
V = volume, in liters, of solution at time of burst.

If the accident is not terminated in some other way, the total number of fissions in the plateau as a function of the duration of the plateau is —

$$F_p = 4.6 \times 10^{19}(t^{.02} - 1) \qquad \text{Eq. 18-4-8}$$

where:

F_p = total fissions in the plateau.
t = duration of the plateau.

Such calculations are useful for design purposes, but the only method for analysis of a given occurrence is appropriate dosimetry. The energy releases for several past criticality accidents, for the most part involving solutions, are given in Table 18-4-5.

TABLE 18-4-5
ENERGY RELEASE OF PAST CRITICALITY ACCIDENTS

	Characteristics of Fissile Material System				Number of Fissions (x 10^{17})	
Location	Form	Mass, kg Fissile	Volume, liter	Duration of Excursion (min)	Initial Burst	Total
Y12	$UO_2(NO_3)_2$ (a)	2.5	56	13	$\sim$ 0.1	13.0
LASL	Pu/Organic	3.3	168	< 1	1.5	1.5
IF	$UO_2(NO_3)_2$ (a)	34.5	800	20	1.0	400.
IF	$UO_2(NO_3)_2$ (a)	8.0	40	< 1	$\sim$ 0.6	6.0
Hanford	Pu Complex	1.5	$\sim$ 60	2220	$\sim$ 0.1	8.0
Wood River	$UO_2(NO_3)_2$ (a)	2.6	$\sim$ 70	< 1	1.1	1.3
Windscale	Pu/Organic	2.5	$\sim$ 100	< 1	0.01	0.01
ORNL	$PU(NO_3)_4$	1.15	64	< 1	$\sim$ 0.8	0.8
ORNL	UO_2F_2	18.3	55	< 1	0.5	0.5
ORNL	$^{233}UO_2(NO_3)_2$	$\sim$ 1.0	5.8	< 1	0.11	0.11

(a)Uranium enrichment $\sim$ 93 wt% ^{235}U.

Solids are somewhat less predictable than solutions. There may be no other way for shutdown of such an accident than dispersal induced by self-generated energy. Powders may require relatively little energy, but metallic units may be quite difficult to disperse. Large pieces of metal or smaller pieces placed together in a critical configuration could result in severe energy releases.

ACCIDENT DOSIMETRY

Criticality accidents present a number of intricate dosimetry problems. The radiation field is complex (neutron-gamma-beta), and doses of up to several thousand rads may be present. Information on the neutron energy spectrum is required, also.

The advantages of dose measurements include the following:

- Separation of those persons requiring immediate attention from those who will show only mild clinical effects or have received no significant dose. This process is known as triage.
- Determination of the need for specialized aid such as bone-marrow grafts.
- Handling of litigations that might arise.
- Long-term radiation effects and future employment considerations.

One indicator of thermal neutron dose that always is available is the activity of ^{24}Na in the blood. ^{38}Cl also is present. This activity is the result of (n,γ) reactions of thermal neutrons with stable ^{23}Na and ^{37}Cl in the body. A portable survey meter or whole-body counter may be used for initial sorting. For sufficiently high exposures (> 100 rad), a 10-ml blood sample analyzed on a γ-spectrometer will suffice. A conversion factor of 5.2×10^{-6} μCi/ml of blood/rad has been suggested. Another immediate indicator is the level of ^{128}I in the thyroid, where iodine concentrates in the body. A survey meter may utilized in determining the level; however, level must be determined fairly soon after the accident because of the short half-life of ^{128}I.

Early segregation of irradiation victims will be accomplished more easily with a sensitive monitor. Criticality dosimeters usually contain indium foils that utilize the $^{115}In\ (n,\gamma)\ ^{116m}In$ reaction for thermal neutrons. Fast neutrons may be detected from resonance or threshold reactions. The latter reactions are energetically possible only with incident neutrons above a certain energy. A number of such detectors with varying thresholds allow a great deal of information to be obtained about the neutron energy distribution. The $^{32}S(n,p)^{32}P$ reaction almost always is utilized. Intermediate and thermal energy neutrons also are detected by bare and cadmium-covered gold foils. Table 18-4-6 lists characteristics of some neutron detectors and their effective energy region. Fissile or fissionable materials may be used if a layer of the material is coated on plastic and if the tracks made on the plastic by escaping fission products are counted via a microscope. A combination of isotopes with different thresholds for fission may be employed, just as with activation foils. This method is time consuming and bulky and has practical application only in posted dosimeters, not those worn. It is also possible to do Initial sorting also is possible by the examination of belt buckles, rings, or other metal personal effects that have become activated.

TABLE 18-4-6
CHARACTERISTICS OF VARIOUS NEUTRON DETECTORS

Detector	Shield	Reaction	Energy Region	Half-Life
Indium	–	$^{115}In\ (n,\gamma)\ ^{116m}In$	Thermal + Resonance	54.0 min
Europium	–	$^{151}Eu\ (n,\gamma)\ ^{151}Eu$	Thermal	9.2 hr
Gold	–	$^{197}Au\ (n,\gamma)\ ^{198}Au$	Thermal + Resonance	2.7 day
Sodium	–	$^{23}Na\ (n,\gamma)\ ^{24}Na$	Thermal + 2.8 kev Resonance	15 hr
Gold	Cadmium	$^{197}Au\ (n,\gamma)\ ^{198}Au$	412 kev Resonance	2.7 day
Copper	Indium + Cadmium	$^{63}Cu\ (n,\gamma)\ ^{64}Cu$	2 ev-1 Mev Resonances	12.7 hr
Indium	Cadmium	$^{115}In\ (n,\gamma)\ ^{116m}In$	1.45 ev Resonance	54.0 min
Indium	Indium + Cadmium	$^{115}In\ (n,n')\ ^{115m}In$	$\geq$ 1.6 Mev	4.5 hr
Sulphur	–	$^{32}S\ (n,p)\ ^{32}P$	$\geq$ 3.2 Mev	14.3 day
Nickel	–	$^{58}Ni\ (n,p)\ ^{58}Co$	$\geq$ 3.4 Mev	71.3 day
Aluminum	–	$^{27}Al\ (n,p)\ ^{27}Mg$	$\geq$ 5.3 Mev	9.5 min
Magnanese	–	$^{24}Mg\ (n,p)\ ^{24}Na$	$\geq$ 6.3 Mev	15 hr
Aluminum	–	$^{27}Al\ (n,\alpha)\ ^{24}Na$	$\geq$ 8.1 Mev	15 hr

Gamma dosimeters must have the capability of covering the range of normal occupational exposures (< 1 rad) up to possible accidental exposures (∿ 5000 rad). The most reliable method presently utilizes thermoluminescent dosimeters (TLD), which are compounds such as LiF, CaF_2, and $CaSO_4$ that contain minute amounts of impurities. When exposed to gamma rays, some electrons are excited to higher energy levels. When the TLD is heated to the proper temperature, light photons are emitted as the electrons are de-excited; and these protons can be measured to determine original gamma dose. Another method consists of glass rods that also take advantage of changes in electron energy measured as flourescent emissions under ultraviolet light. If some rods are encased in a heavy gamma shield, information can also be obtained concerning the incident gamma energies. Some accident dosimeter designs are illustrated in Figure 18-4-13.

An immediate indication of gamma dose can be obtained by the use of self-reading pocket dosimeters. These units are small ion-chambers (Figure 18-4-14), which may cover various ranges up to 1000R. Two dosimeters that cover different ranges should be used. These units are durable, rugged, and conveniently worn; however, if they are subjected to shock, they should be read and recharged, since a shock-induced discharge could result in false high readings.

Accident dosimeters must be more sensitive than the average personnel monitoring dosimeters because they must record and/or indicate exposures to large doses of radiation that might result in a criticality accident.

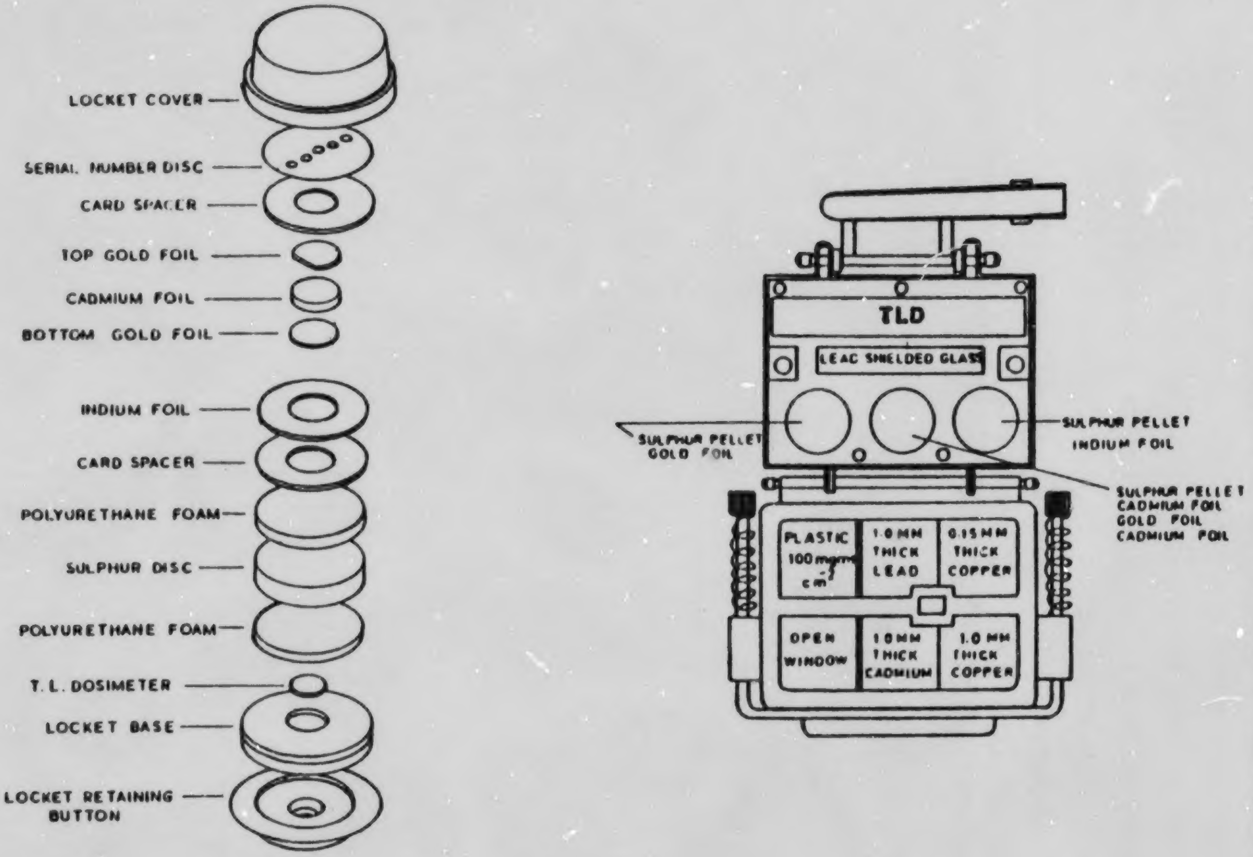

LOCKET COVER
SERIAL NUMBER DISC
CARD SPACER
TOP GOLD FOIL
CADMIUM FOIL
BOTTOM GOLD FOIL
INDIUM FOIL
CARD SPACER
POLYURETHANE FOAM
SULPHUR DISC
POLYURETHANE FOAM
T. L. DOSIMETER
LOCKET BASE
LOCKET RETAINING BUTTON
TLD
LEAD SHIELDED GLASS
SULPHUR PELLET GOLD FOIL
SULPHUR PELLET INDIUM FOIL
SULPHUR PELLET CADMIUM FOIL GOLD FOIL CADMIUM FOIL
PLASTIC 100 mg cm^{-2}
1.0 MM THICK LEAD
0.15 MM THICK COPPER
OPEN WINDOW
1.0 MM THICK CADMIUM
1.0 MM THICK COPPER

Figure 18-4-13. Two types of accident dosimeters.

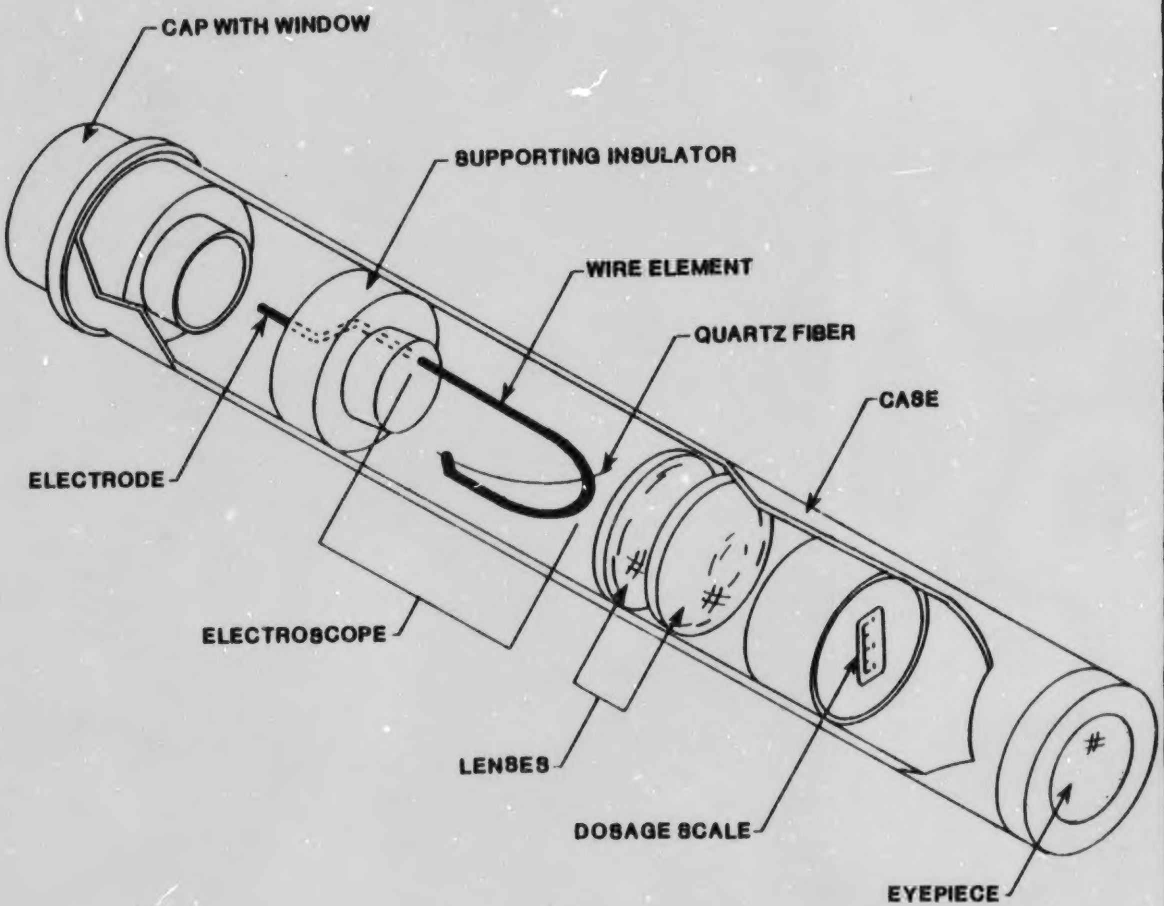

CAP WITH WINDOW
SUPPORTING INSULATOR
WIRE ELEMENT
QUARTZ FIBER
CASE
ELECTRODE
ELECTROSCOPE
LENSES
DOSAGE SCALE
EYEPIECE

Figure 18-4-14. Self-reading dosimeter (cutaway).

ESTIMATE OF EXPOSURE

Even with sufficient dosimetry available, estimates of the exposure received may be difficult. A final determination of absorbed doses will require a detailed analysis of the accident, radiation spectrum, orientation and distances of personnel at the time of the event, and clinical effects observed in those exposed. Some rough estimates can be made, however, from semi-emperical equations that have been developed. If the total number of fissions occurring has been determined from an estimate such as that obtained from Equation 18-4-7 or from stationary dosimeters near the accident, the following equations can be used:

$$D_\gamma = 2.1 \times 10^{-20} \frac{N}{d^2} e^{-3.4d} \qquad \text{Eq. 18-4-9}$$

and

$$D_n = 7 \times 10^{-20} \frac{N}{d^2} e^{-5.2d} \qquad \text{Eq. 18-4-10}$$

where:

D_γ = gamma dose (rem).
D_n = neutron dose (rem).
N = number of fissions.
d = distance from source (meters).

When shielding is present, these doses must be reduced. The reduction factors for concrete are listed in Table 18-4-7. Again, there is no substitute for actual data from accident monitors. Equations such as 18-4-9 and 18-4-10 should be used to estimate doses for triage purposes.

TABLE 18-4-7

DOSE REDUCTION FACTORS TO BE USED WITH EQUATIONS 18-4-9 and 18-4-10.

Concrete Reduction Factors		
Thickness	Gamma	Neutron
First 8 inches	2.5	2.3
First 1 foot	5.0	4.6
Each additional foot	5.5	20

EXAMPLE

Given: A worker is standing 10 meters from a mixing tank having no shielding. A criticality accident occurs, and the worker is exposed to 10^{17} fissions before evacuating.

Find: Estimate of total dose received by the worker.

Solution: Gamma dose:

$$D_\gamma = 2.1 \times 10^{-20} \frac{(10^{17})}{(10/1000)^2} e^{-3.4\,(10/1000)}$$

$$= \frac{2.1 \times 10^{-3}\ (0.9666)}{10^{-4}}$$

$$D_\gamma = 20.3 \text{ rem.}$$

Neutron dose:

$$D_n = \frac{7 \times 10^{-20}\ (10^{17})}{(10/1000)^2} e^{-5.2\,(10/1000)}$$

$$D_n = \frac{7 \times 10^{-3}\ (0.9493)}{10^{-4}}$$

$D_n = 66.5$ rem.

Total Dose = 20.3 + 66.5 = 86.8 rem (sum of gamma and neutron doses).

BIOLOGICAL EFFECTS

Radiation effects may be divided conveniently into acute (short-term) effects and delayed (long-term) effects. Delayed effects manifest themselves from months to years after the exposure. The acute effects are of interest in radiation accidents because their clinical symptoms are understood fairly well and can reveal much about exposures received.

Although these symptoms are complicated by a number of factors, the chronological sequence of events in a large whole-body exposure can be described in general. The sequence usually is divided into four states:

1. The initial state ..... 0 to 48 hours postexposure.
2. The latent stage ...... 48 hours to 2-3 weeks postexposure.
3. The manifest illness stage ... 2-3 weeks to 6-8 weeks postexposure.
4. The recovery stage .... 6-8 weeks to several months postexposure.

The amount of radiation received governs the symptoms observed in each stage. There is about a 50% chance of death within two months for whole-body exposures greater than 300-400 rem. For doses less than 100 rem, there usually are no observable effects. Various clinical effects of acute exposures are presented in Table 18-4-8.

TABLE 18-4-8
PHYSIOLOGICAL RESPONSE TO SHORT-TERM RADIATION EXPOSURE*

Dose (Rads)	Response
20-100 whole-body	Changes in relative numbers of circulating white blood cells. Also a few blood cells show chromosome changes
200-400 whole-body	Severe reduction in white blood cells. Nausea and vomiting. Loss of hair. Some deaths within sixty days due to increased susceptibility to infection.
600 whole-body	Fifty percent of those exposed die within thirty days. Bone marrow, the source of white blood cells, is destroyed. Some dysentery or diarrhea.
600-1000 skin	Skin reddening, then loss of skin.
1000-2000 whole-body	Temporary sterility. Lining of intestine destroyed. Diarrhea severe. Death within two weeks.
2000 and more whole-body	Central nervous system severely damaged. Death within hours.

*From Parrington and Patterson.

IMMEDIATE RESPONSE

In initial control of an incident planning, backed by design and operational requirements, will be of great assistance. One characteristic of most criticality accidents that have occurred has been the rather extended period before full assessment was made and the incident brought under control. Table 18-4-9 depicts a possible time schedule of actions after an accident.

TABLE 18-4-9

POSSIBLE TIME SCHEDULE OF ACTIONS AND ACTIVITIES AFTER A CRITICALITY ACCIDENT[1]

Time after Accident[2]	Probable Actions, Activities, or Events
10 min	1. All employees have evacuated.
2 hr	1. Source of reaction has been located. 2. Radiation boundaries have been established. 3. Checking of personnel monitors has been started to determine those who potenially have been seriously exposed. 4. Personnel decontamination has been initiated. 5. Problems of possible fallout are under review. 6. Public-relations activities have started. 7. Mutual-assistance agreements have been implemented as necessary.
6 hr	1. Reaction has been stopped or it has been determined that it cannot readily be stopped. 2. All employees with potentially high exposures have been located, and medical treatment has been started. 3. Personnel and area dosimetry to determine accurately the exposures of highly exposed personnel is under way.
12 hr	1. Exposures of highly exposed individuals have been determined as well as possible from dosimetry. 2. Cleanup of reaction has started, and plans are being laid for necessary work connected with getting back into operation. 3. Investigation of accident cause is under way. 4. Evaluation of technical aspects of the incident has been started.
24 hr	1. All employees have identified their actions at the time of, and immediately after, the accident as a part of the plant record. 2. Follow-up activities to determine, as well as possible, the doses received by those who were not highly exposed have been initiated.

[1] From H.F. Henry.

[2] The times listed are not target times, but indicate the maximum intervals within which the items enumerated should be initiated or completed, it being recognized that the peculiarities of a specific event will affect these times.

Actions of persons who hear (or see) an alarm should be defined clearly; for example, this is one situation in which such persons may run during evacuation. To run past an incident is not as undesirable as prolonged indecision near an accident.

Ideally, the source location would be given by the alarm; however, one may have to approach the radiation area, watching closely for flare-ups. Respiratory equipment may be necessary. In radiation incidents, no person should intentionally receive more than 25 rems unless efforts to save a life are involved. Key personnel, therefore, initially should avoid receiving any exposure except that absolutely necessary, in order that their services may remain available during the accident. "Sight-seeing" must not be allowed.

Simultaneous with the termination of an incident is the caring for injured or exposed personnel. A safe area must be established, free of contamination and with background radiation levels low enough to allow identification of contaminated clothing or equipment. Long-term activities that involve control of the spreading of contamination, assessment of the extent of damage, and accident ivestigation will come next. Hopefully, the cause can be determined and preventative measures instituted.

HISTORY

In any complex field, experience is an excellent teacher; and much can be learned from review of incidents that have occurred. Close study of case histories can prevent the repetition of past mistakes made in response to accidents and can improve accident prevention.

Criticality accidents have occurred in fuel processing plants, in reactor auxiliary units, and in research reactor facilities. With research reactors, criticality incidents are a normal hazard of operation; therefore, appropriate shielding and other protection have been provided for experimenters and equipment.

Some 30 cases of uncontrolled fission have occurred since the early days of the nuclear industry. Nine persons have received fatal radiation doses, and approximately 30 persons have received doses in excess of 25 rads. The more noteworthy of those which have happened in the United States are discussed below.

Two of the first recorded criticality accidents occurred in 1945 and 1946 at Los Alamos Scientific Laboratory. Both involved "stacking" experiments in which criticality is gradually approached by addition of fissile or reflector materials. In the first of these accidents, a cube of fuel intended for the corner of a critical assembly was dropped accidentally into its center. The resultant total-body dose to the experimenter was about 500 rads and was subsequently fatal.

In the other accident, a physicist was demonstrating criticality to another scientist and six observers also present in the room. The procedure was to surround a mass of fissionable material with two hemispheres of beryllium reflector. One of the hemispheres containing the material was placed on a table and the other was to be brought slowly down until the assembly was just subcritical. A screwdriver was used as a lever to lower the hemisphere. When the two halves were approximately one inch apart, the screwdriver slipped; the upper hemisphere fell; and prompt criticality occurred, with a blue flash and heat wave. The experimenter separated the assembly with his hands. He received a dose of approximately 1500 rad (5000 rem) and died nine days later. The other individuals received doses of 20-200 rad, but all survived. This incident illustrates the need for proper equipment and operating procedures.

There also have been several accidents at processing facilities. Two of the most important occurred in 1958. In an incident at the Y-12 Plant at Oak Ridge National Laboratory, an employee drained wash water, supposedly containing little uranium, from a pipe into a 55-gallon drum. Because of operational problems, however, a significant amount of highly enriched uranium had accumulated in the pipe. Although the dimensional arrangement had precluded criticality when the material had been in the pipe, this was no longer the case when the solution was drained into the drum. Fortunately, the proper operation of installed alarm systems and adherence to the emergency plan prevented any fatalities. Also, valuable dose information obtained from badges allowed the eight men who received doses of 20 to 365 rads to be promptly identified and hospitalized.

Another Los Alamos accident, which resulted in the fatality of one employee, came about when a chemical operator unknowingly poured a solution that contained an unsafe quantity of plutonium into a waste recovery tank and started a stirrer. Criticality ensued. The operator was knocked down by the heat release, but remained near the tank until aid reached him. His dose was estimated to have been above 2000 rads (∿ 12,000 rem), and he succumbed two days later. The accident revealed that this facility had some important shortcomings such as the failure to consider the potential for human error and the inadequate use of safe geometries for process vessels.

Probably the most violent criticality incident to date, one of only two significant events at reactors, occurred on the Stationary Low Power Reactor No. 1 (SL-1) at Idaho Falls, Idaho, in January 1961. Prompt criticality resulted when a reactor operator manually withdrew a control rod further than the allowable limit during maintenance operations. The ensuing steam explosion blew shield plugs from the top of the reactor vessel, actually lifting the vessel into the air. All three of the military personnel present were killed by the blast, one of them actually being impaled on the ceiling of the building. Radiation levels in the building exceeded 1000 R/hr, and the bodies themselves read 100 to 500 R/hr at six inches. The subsequent control and cleanup activities took well over a year. Individuals involved in health physics recovery actions received exposures significant enough to warrant limiting their future exposures. The experience revealed much about the need for sufficient numbers of trained emergency teams and high-level monitoring instruments in these situations.

EXERCISES

1. During a subcritical multiplication measurement for a new mixing tank, the count rate is 100 cps. At this point, k_{eff} is calculated to be 0.965. What would be the expected count rate when the safety limit of 0.980 is reached?

2. A proposed piping system is to be installed in a fuel reprocessing plant. Describe the various types of limits that might be placed on its design to assure subcriticality. Use Table 18-4-3.
3. A research facility must ship two subcritical mixtures of plutonium solution to a solvent extraction plant for recovery of plutonium. Describe methods for ensuring a safe trip.
4. What would be your recommendation for a plan to store several experimental UO_2 fuel rods, 15% enriched, in a 30-cm-diameter cylindrical array in a storage pool? The elements contain a total of 1.8 kg of ^{235}U. Use Figures 18-4-3 and 18-4-4.

MATERIALS

None.

PROCEDURES

SIMULATED CRITICALITY EVENTS

These procedures involve the student in the actions to be taken in two simulated, but real-life, criticality situations. The student should write a one- or two-page paper that gives the solution for each of the two problems.

1. During a critical experiment a physicist accidentally places a vial of plutonium powder in the wrong place with a pair of long forceps, bringing the system very close to criticality. Realizing the mistake, the physicist steps close to the pile to determine how to correct the problem. Criticality ensues. What happened and what should have been done?
2. The criticality alarm sounds, and a worker is exposed to an accident. During hasty evacuation, several things happen?
    - The worker's badge is lost.
    - The worker trips.
    - The worker's self-reading dosimeter discharges.

   Describe the proper action in estimating dosage to this person, who at the time of the accident was standing behind a one-foot concrete wall known to have been 15 meters from the accident. A remote accident recorder indicates that total fissions of 10^{18} were generated before accident termination. (Hint: Remember Equational 18-4-9 and 18-4-10.)

DATA TABLES

None.

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REFERENCE MATERIALS

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TEST

1. Define the following terms:
   a. Criticality Accident.

   b. Multiplication factor.

   c. Critical mass.

   d. Prompt critical.

   e. Single parameter limit.

   f. Lattice.

   g. Double contingency principle.

   h. Double batching.

   i. Bird Cage.

   j. Triage.

k. Fission spike.

2. Briefly discuss the effects of geometry on critical mass.

3. List the three common fissile materials and the minimum critical mass of metal for each.

4. Describe what happens in a supercritical system.

5. For a given enrichment, what are four other factors that can be limited to prevent criticality in lattices of fissile material?

6. Discuss possible ways to prevent criticality in a fuel reprocessing plant by design precautions.

7. Describe two types of criticality alarms, and explain where they might be used.

8. List five administrative practices that can assist in the prevention of critical accidents.

9. Sketch and explain a curve of fission rate versus time during a criticality accident.

10. Calculate the estimated neutron dose to a worker standing 40 meters from a criticality accident that generates 10^{17} fissions. Assume no shielding. Use:

$$D_n = 7 \times 10^{-20} \frac{(N)}{d^2} e^{-5.2d}$$

11. Generally outline the initial (first 15-30 minutes) response to a criticality alarm.

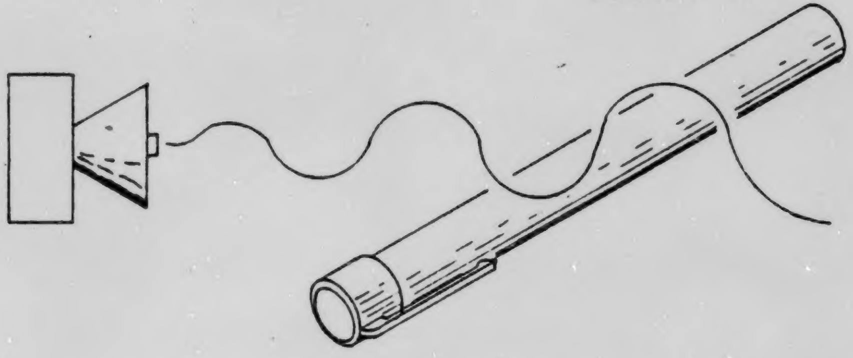
NUCLEAR TECHNOLOGY

MODULE 18 - 5

CONTROL OF RADIOLOGICAL HAZARDS

RADIOLOGICAL EMERGENCIES

COURSE 18



CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

COURSE 18 RADIOLOGICAL EMERGENCIES

	Module 18-1	General Procedure for Radiological Emergencies
	Module 18-2	Emergency Equipment for Nuclear Facilities
	Module 18-3	Surface Contamination – Decontamination
	Module 18-4	Criticality Control
⇨	Module 18-5	Control of Radiological Hazards
	Module 18-6	Emergency Planning for Nuclear Facilities
	Module 18-7	Emergency Drills for Nuclear Facilities

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INTRODUCTION

Any nuclear activity that involves the use of a radioactive material in open form releases some small amount of that substance to the surroundings during normal operation. Under accident or failure conditions, however, there is an increased potential for more hazardous environmental releases. This is especially true of facilities that house high levels or large volumes of radioactive materials.

This module discusses the means by which radioactivity that results from radiological emergencies can enter the environment. The discussion includes the various pathways of radiation to man, as well as techniques for monitoring of effluent releases and calculation of resulting radiation doses.

MODULE PREREQUISITES

The student should have completed Course 1, "Radiation Physics"; Course 2, "Radiation Protection I"; Course 11, "Radiation Detection and Measurement"; Course 17, "Radiation Protection II"; and all previous mouldes of this Course.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Describe the sources of background radiation in the environment.

2. Discuss the contents of an environmental appraisal.
3. Explain the means by which radioactive materials may be dispersed in the atmosphere and calculate the concentrations of radioactive materials in air from a release under given meteorological conditions.
4. Calculate doses from given concentrations of radioactive materials in air or water.
5. Identify the various exposure pathways to man from liquid effluents.
6. Discuss the particular problems involved with dairy products in the food chain, including metabolic behavior of radionuclides.
7. List the basic monitoring and sampling techniques for environmental radiological surveillance.
8. Describe the concept behind MPBB and MPC, and list the values for two radionuclides in air and water for unrestricted areas.
9. Define the following terms:
    - Natural background.
    - Diffusion factor.
    - Food chain.
    - Concentration factor.
    - Foliar deposition.
    - Critical organ.

SUBJECT MATTER

Man lives in an environment in which delicately balanced geological, meteorological, and biological factors create the conditions necessary for human life. This environment evolves through a process of continuous, often subtle, and dynamic change on all levels from microscopic cell division to major atmospheric phenomena. There is no clear distinction between what often are called "natural" changes and those that come about as a result of attempts to improve human comfort and knowledge. Nevertheless, the fact is that mankind, unlike other species, can accidentally produce large environmental disturbances that may have a widespread and harmful effect. The uncontrolled release of radioactive material is an example of such an event.

NATURAL BACKGROUND

Opponents of nuclear facilities quite often cite as one of their concerns a fear of the release of radioactive materials into the environment. It does not appear to be common knowledge that everyone constantly is being exposed to radiations of natural origin. Before the results of accidental radioactive emissions are examined, the sources and levels of these natural "background" radiations must be studied.

The three sources of natural radiation exposures are (1) cosmic radiation, (2) external terrestrial sources, and (3) natural sources within the body. Cosmic radiation comes from outer space in the form of high-energy protons that interact with molecules in the stratosphere to create secondary radiations. Their intensity is, quite logically, a function of the height above sea level, with higher altitudes being less protected by the earth's atmosphere. Figure 18-5-1 illustrates the approximate increase in cosmic-ray dose with altitude. There is also a smaller variation with geographical latitude. The increase in dose for those who fly often or who live at higher altitudes easily can be seen.

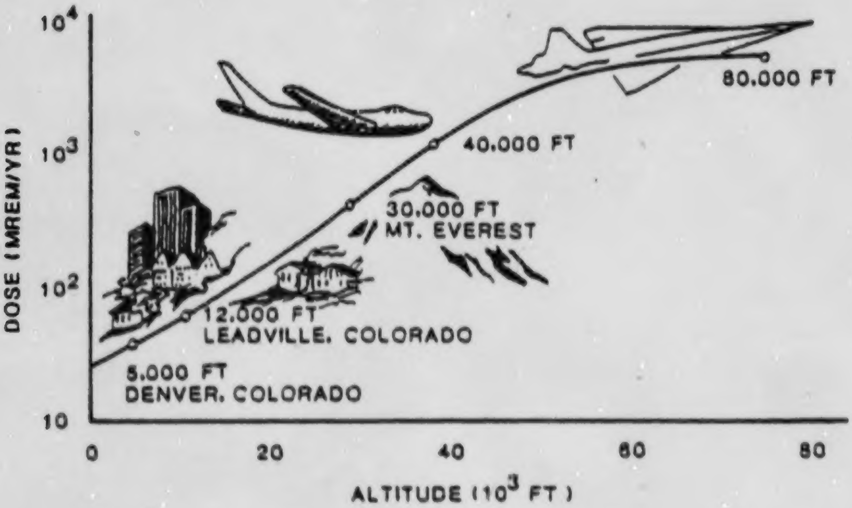

Figure 18-5-1. Increase in cosmic-ray dose with altitude.

External gamma radiation also comes from naturally-occurring, long-lived radionuclides created during the birth of the universe. Uranium and thorium, for example, are among the most common elements in the earth's crust. Along with their daughter products, they account for a large amount of external background exposure.' Some regions of the world – such as Kerala on the east coast of India and the state of Rio de Janeiro, Brazil – have such high concentrations of these elements that inhabitants receive 500 to 1500 mrem annually. A measurable amount of such radioactivity is present in all building materials, especially if uranium- or thorium-bearing sands are used. Background radiation also may come from shorter-lived radionuclides, which continuously are being formed by cosmic activation. These radionuclides include ^{3}H, ^{7}Be, ^{14}C, and ^{40}K. Internal exposure due to natural radiation is a result of ingestion of these, as well as such radionuclides as ^{137}Cs, ^{90}Sr, and ^{87}Rb, which have been injected into the atmosphere during the testing of nuclear weapons. The latter is an example of background radiation that was introduced artificially but will be a part of the natural environment for several years.

ENVIRONMENTAL APPRAISALS

Prior to the building or extensive enlargement of a facility that handles radioactive materials, an environmental impact report may be required. This is certainly true of major operations such as nuclear power plants. A written document of this type is the result of considerable effort. Its purpose is to establish the specific characteristics of the site and its immediate surroundings in order that normal and postulated accidental releases can be evaluated for their effect on the environment. First, an extensive study is made of the area; both direct measurements and available records are used. Information required will include data on the following site characteristics:

- Geography – site location and terrain.
- Ecology – plant and animal life.
- Demography – population density.

- Meteorology — weather patterns.
- Hydrology — water movement.
- Geology — mineral deposits and subsurface structures.
- History and culture — archaeological to recent.
- Background radiations — types and reference concentrations.
- Aesthetics — visual appeal.
- Economy — numbers and types of businesses.

Such data are combined with a plant safety analysis, which describes the sources and quantities of radioactivity that may be released during normal and accident situations. The result is an estimate of the environmental effects of a complete spectrum of possible releases. It covers property and business damages as well as individual and population doses.

In addition to various analyses, the report describes proposed monitoring systems necessary to ascertain the precise concentrations of effluent releases and their movement in the environment. Periodic sampling, and automatic monitoring equipment normally are required for comprehensive measurements. The environmental report also may include the details of a facility emergency plan for limiting the consequences of an accidental release.

ATMOSPHERIC DISPERSION OF RADIOACTIVITY

The most important exposure path immediately following a nuclear emergency is likely to be through atmospheric releases. The magnitude of the external dose to the population depends upon factors such as meteorological conditions, distance from the release point, and radionuclides contained in the cloud. Exposure occurs through inhalation of contaminated air or, under extreme conditions, through beta-gamma exposure from a passing radioactive cloud. Deposition on plants also may result in contamination of man's food supplies; this is discussed in more detail later in this module.

To evaluate the consequences of a release of radioactivity to the atmosphere, one must track the effluent through space and time. Dispersion of gases or aerosols is caused by turbulent motion of the air due to wind and temperature. The ground-level concentration of radioactivity downwind of an elevated source can be calculated from Equation 18-5-1.

$$\chi(x,y) = \frac{Q}{\pi\sigma_y\sigma_z\bar{u}} \exp - \left[\frac{y^2}{2\sigma_y^2} + \frac{h^2}{2\sigma_z^2} + \lambda t \right]$$

Equation 18-5-1
(Equation = Eq.)

where:

χ = concentration (curies/m^3) at a point x meters downwind and y meters crosswind from the source.
Q = source strength in Ci/second.
σ_y,σ_z = crosswind and vertical dispersion coefficients (m).
$\bar{u}$ = mean wind speed (m/sec).
h = height of release above surface (m).
λ = isotope decay constant (hr^{-1}).
t = transit time from stack to distance (hr).

The dispersion coefficients represent the stability conditions of the atmosphere and the complications of terrain.

For a high degree of accuracy, site measurements of σ_y and σ_z are required; however, the curves in Figures 18-5-2 also can be used effectively. These curves are the results of measurements made by Pasquill in the classifying of σ_y and σ_z according to various degrees of stability, as defined in Table 18-5-1. The resulting theoretical surface concentration pattern is that shown in Figure 18-5-3.

Equation 18-5-1 can be used only as long as there are no major changes in wind direction, wind speed, or temperature stability. In an accident situation, all of the data needed on the atmospheric condition rarely would be available. When no specific data are available, the maximum possible concentration must be assumed at all distances downwind from the release. Figures 18-5-4 through 18-5-7 are a series of graphs that allow the calculation of worst-case downwind concentrations at various times during an elevated release. Notice that the ordinate is presented as χ/Q (sec/m^3), called the "diffusion factor." This can be multiplied times the release rate Q to find the concentration. Figures 18-5-8 and 18-5-9 are for ground-level releases. Presentation of the curves in this manner makes χ/Q independent of release magnitude. NOTE: Decay is not accounted for in these curves.

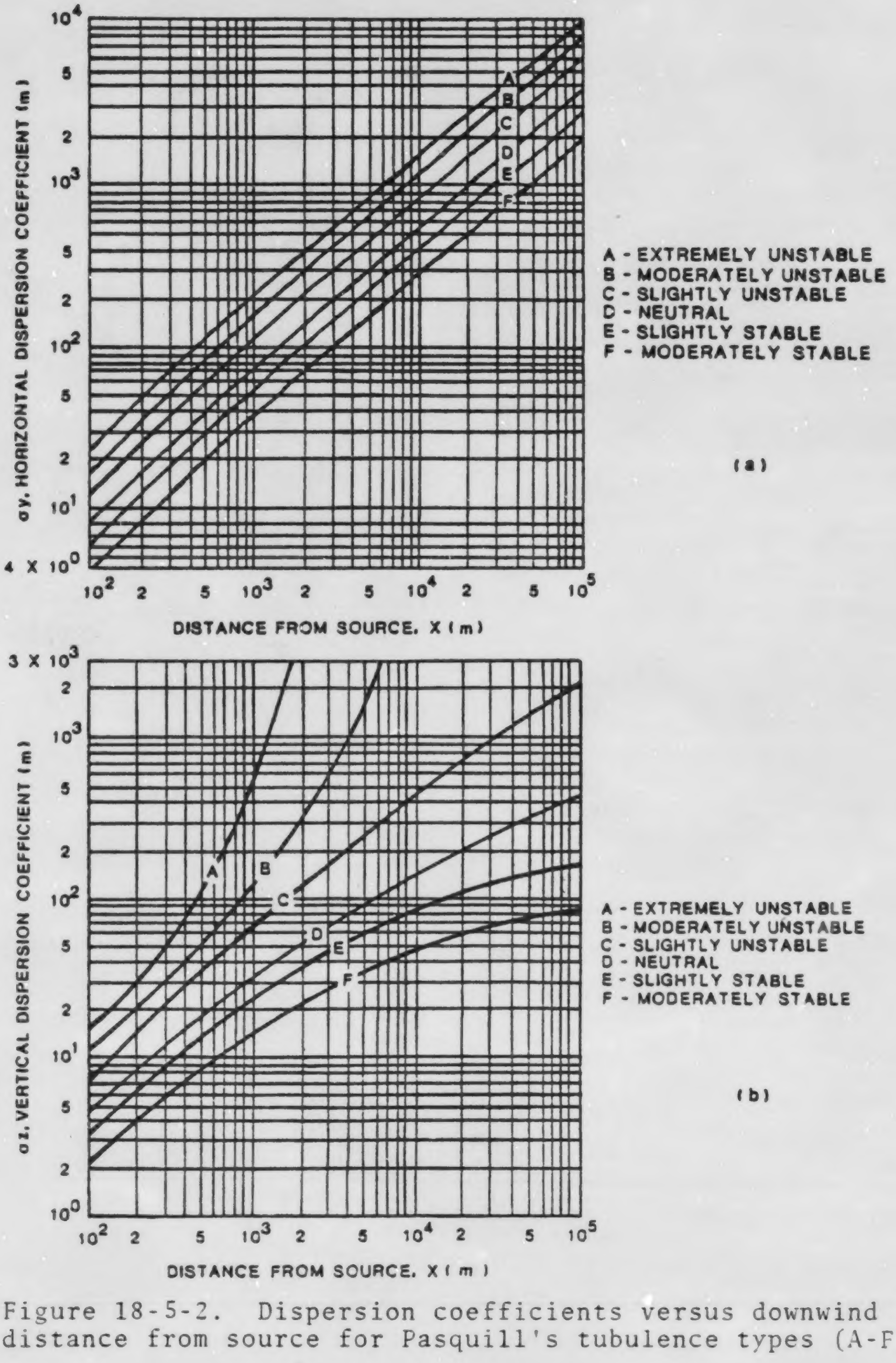

Figure 18-5-2. Dispersion coefficients versus downwind distance from source for Pasquill's tubulence types (A-F).

TABLE 18-5-1

RELATION OF STABILITY TYPES TO WEATHER CONDITIONS[a]

Surface Wind Speed (m/sec)	Daytime Sunlight			Night-Time Conditions	
	Strong	Moderate	Slight	Thin Overcast or < 3/8 Cloudiness[b]	≥ 3/8 Cloudiness
<2	A	A-B	B	–	–
2	A-B	B	C	E	F
4	B	B-C	C	D	E
6	C	C-D	D	D	D
>6	C	D	D	C	D

[a] Conditions: A, extremely unstable; B, moderately unstable; C, slightly unstable; D, neutral (applicable to heavy overcast, day or night); E, slightly stable; F, moderately stable.

[b] The degree of cloudiness is defined as that fraction of the sky above the local apparent horizon which is covered by clouds.

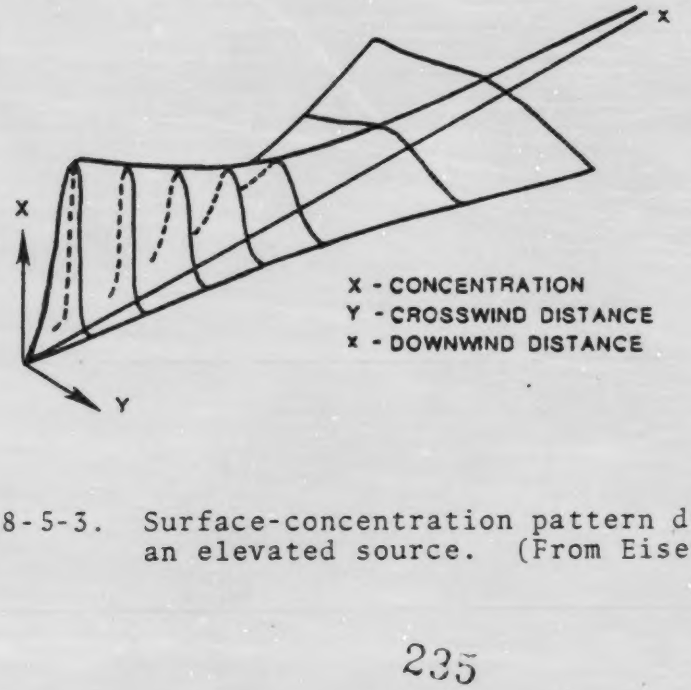

Figure 18-5-3. Surface-concentration pattern downwind from an elevated source. (From Eisenbud.)

EXAMPLE

Given: Iodine-133 is emitted from a 30-meter stack at 3 Ci/sec. It is a bright, sunny day with a steady wind speed of 15 km/hr. Iodine-133 has a half-life of 21 hours.

Find: The concentration of iodine-133 at a point 1 km downwind.

Solution:

Transient time:

$t = \chi/\bar{u}$ $\qquad\qquad$ $\chi = 0.693/21$

$\;\; = 1/15$ $\qquad\qquad$ $\chi = 0.033\ \text{hr}^{-1}$

$t = 0.067$ hr.

From Table 18-5-1 –

$$\bar{u} = 15\ \text{km/hr} \times \frac{1000\ \text{m/km}}{3000\ \text{sec/hr}}$$

$$\bar{u} = 4.2\ \text{m/sec.}$$

Stability type is B.

From Figure 18-5-2a and b –

$\sigma_z = \sim 1.2 \times 10^2$ m

$\sigma_y = \sim 1.6 \times 10^2$ m

$$\chi(x,y) = \frac{3\ \text{Ci/sec}}{\pi(1.2 \times 10^2)(1.6 \times 10^2)(4.2\ \text{m/sec})} \exp - \left[\frac{0}{2\sigma_y^2} + \frac{30^2}{2(1.2 \times 10^2)} + (0.033)(0.067)\right]$$

$$= 1.193 \times 10^{-5} \exp - [3.36 \times 10^{-2}]$$

$$\chi(x,y) = 1.193 \times 10^{-5}\ (0.9670)$$

$$\chi(x,y) = 1.15 \times 10^{-5}\ \text{Ci/m}^3\ (\text{or}\ \mu\text{Ci/cm}^3).$$

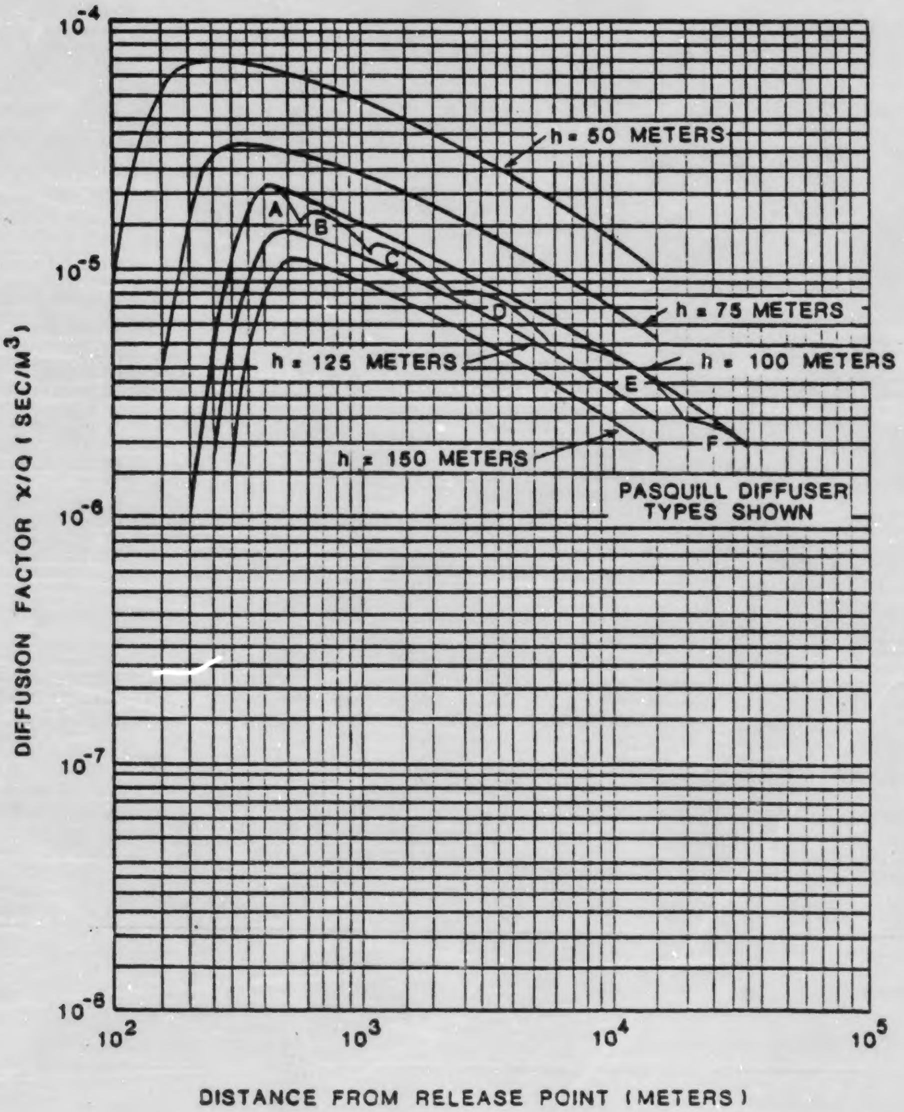

Figure 18-5-4. Elevated release atmospheric diffusion factors 0-8 hour release time.

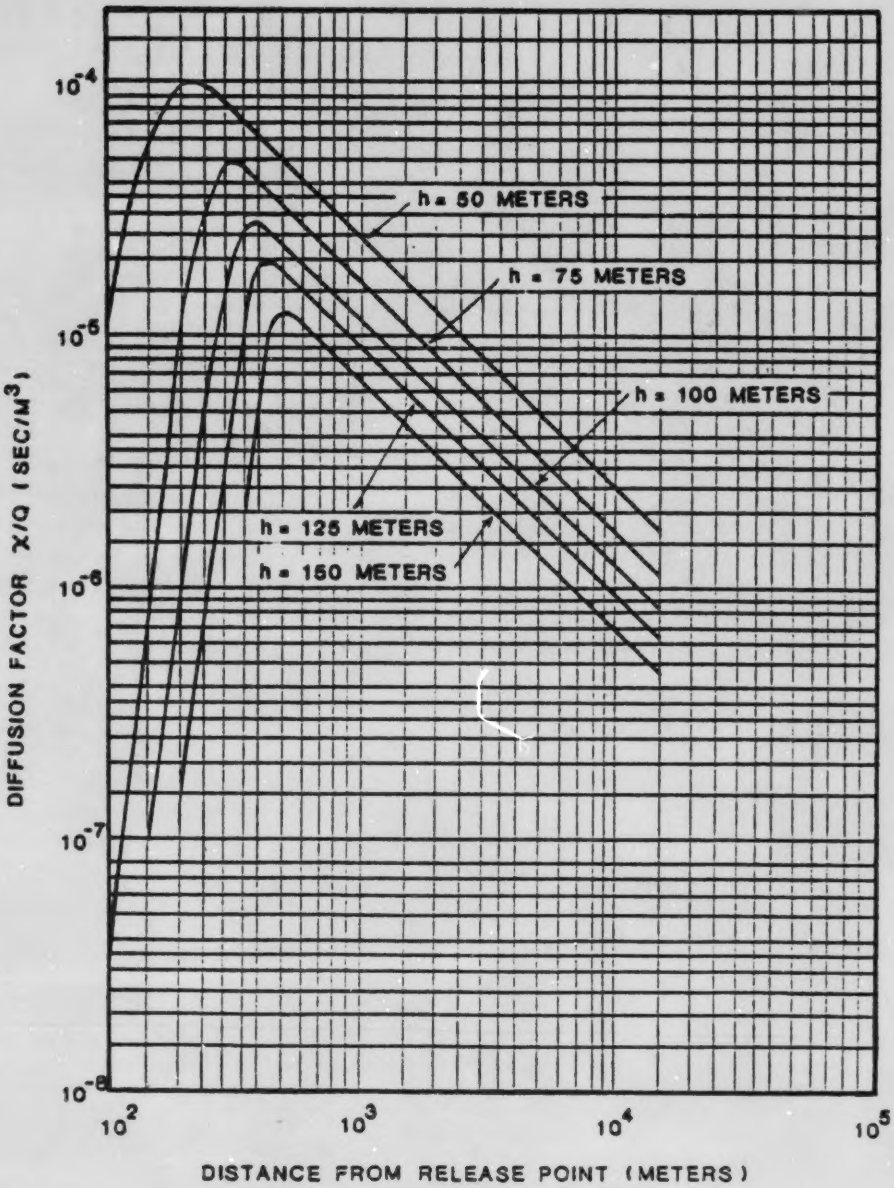

Figure 18-5-5. Elevated release atmospheric diffusion
8-24 hour release time.

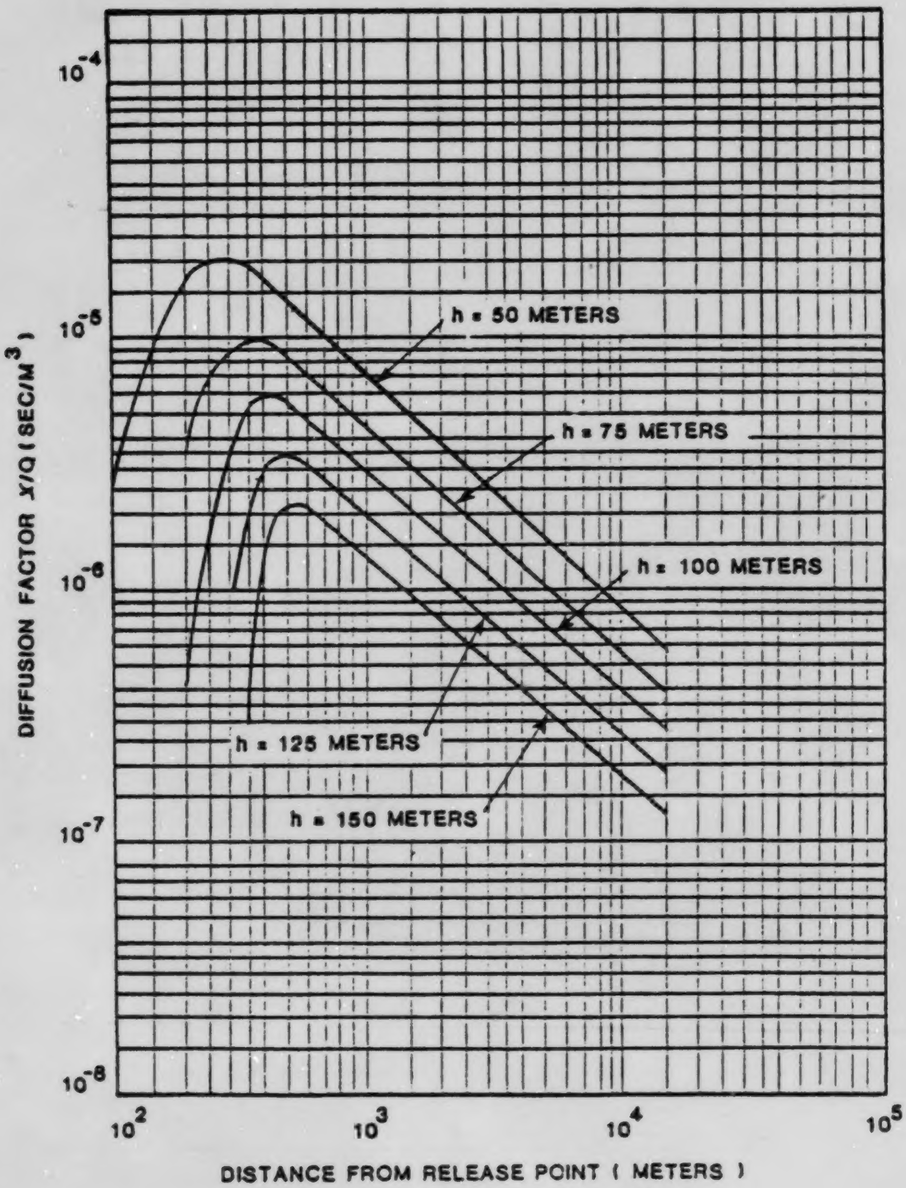

Figure 18-5-6. Elevated release atmospheric diffusion factors 1-4 day release time.

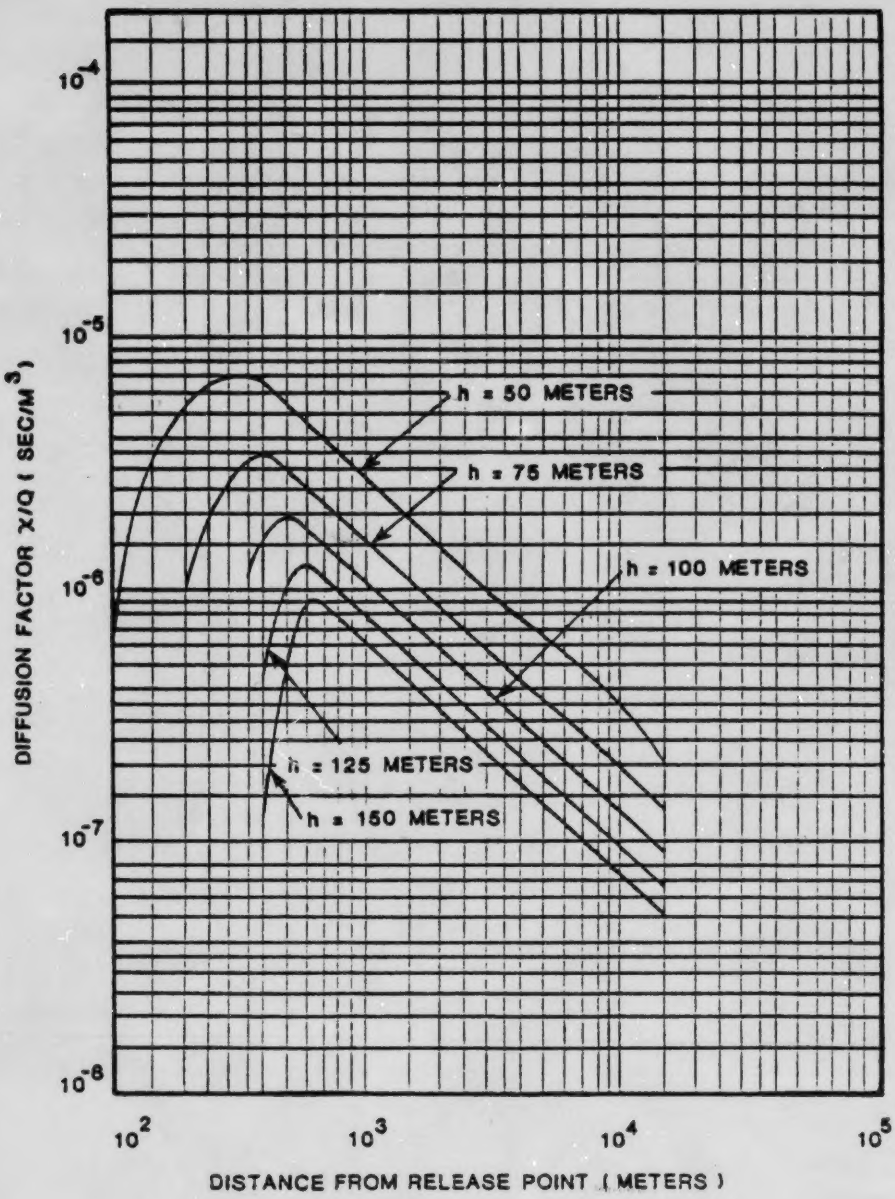

Figure 18-5-7. Elevated release atmospheric diffusion factors 4-30 days release time.

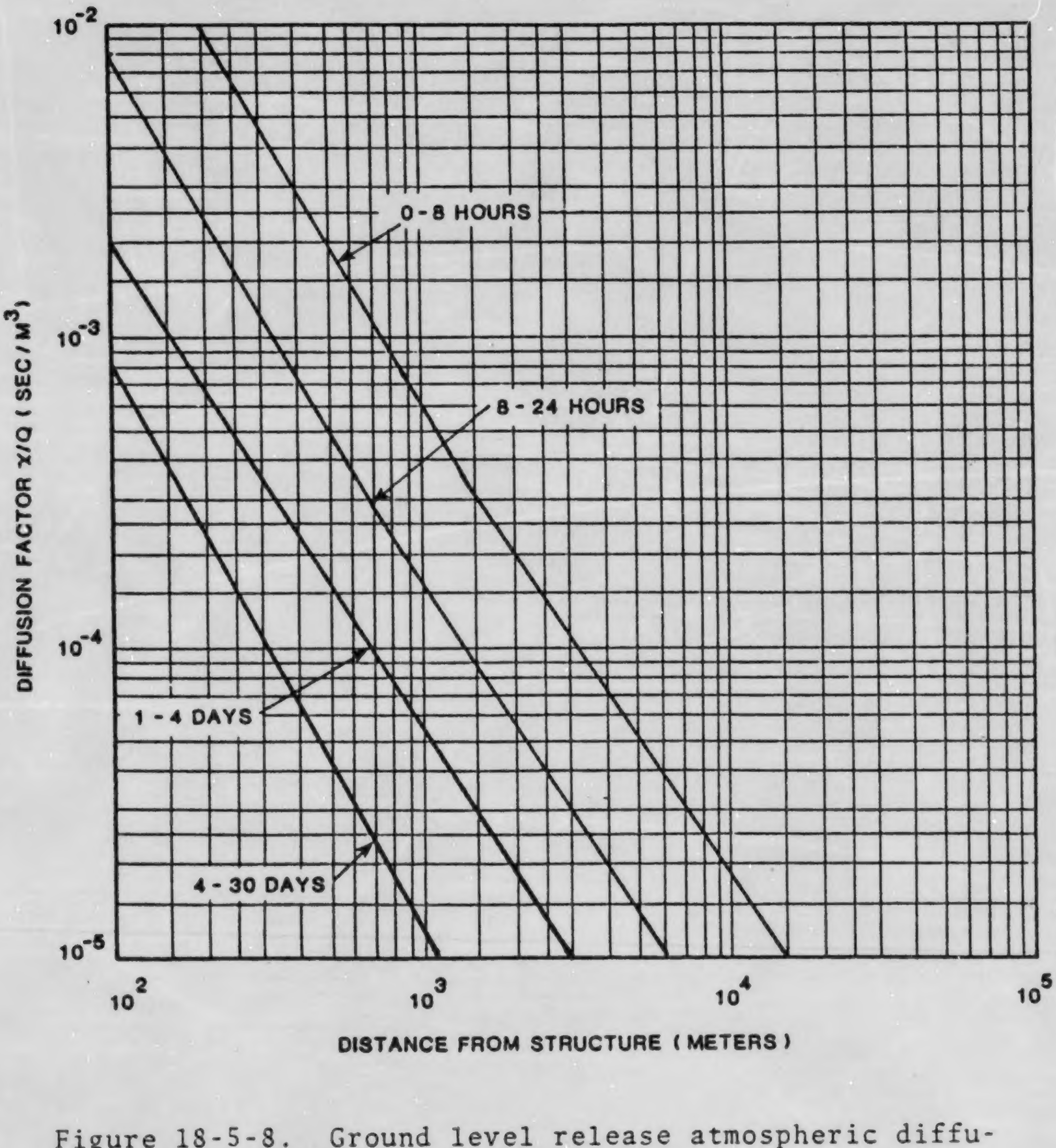

Figure 18-5-8. Ground level release atmospheric diffusion factors for various times following accident.

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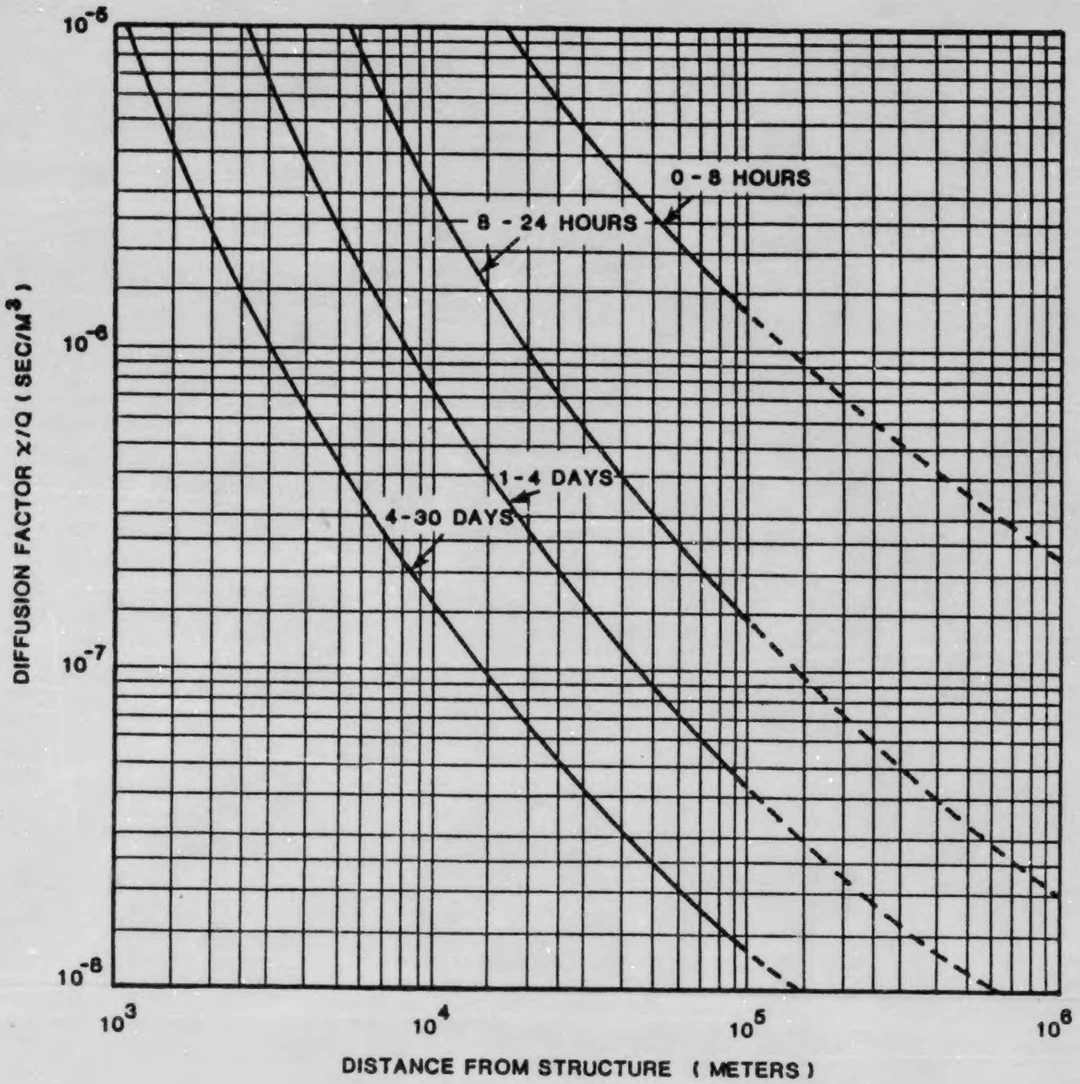

Figure 18-5-9. Ground level release atmospheric diffusion factors for various times following accident.

EXTERNAL DOSE CALCULATIONS

As a radioactive plume passes over the countryside, individuals in its path will receive a dose that depends upon the specific radionuclides in the cloud and their concentrations. Of primary concern in this exposure path are inert gases such as xenon, argon, and krypton, although they have no biological interaction. In other words, radioisotopes of these elements are breathed in and breathed out with no uptake. However, presence in a cloud of high concentration may result in undesirable doses to the skin and whole body. Any airborne radionuclide contributes to external dose; but internal effects normally are limiting for aerosols, as discussed later.

The dose rate to a person standing in a radioactive cloud can be calculated from Equations 18-5-2 and 18-5-3.

$$ {}_{\beta}D'_{\infty} = 0.23\ \bar{E}_{\beta}\chi \qquad \text{Eq. 18-5-2} $$

$$ {}_{\gamma}D'_{\infty} = 0.25\ \bar{E}_{\gamma}\chi \qquad \text{Eq. 18-5-3} $$

where:

${}_{\beta}D'_{\infty}$ = beta dose rate from a semi-infinite cloud of material (rad/sec).

${}_{\gamma}D'_{\infty}$ = gamma dose rate from a semi-infinite cloud of material (rad/sec).

$\bar{E}_{\beta}$ = average beta-particle energy per disintegration in MeV/disintegration.

$\bar{E}_{\gamma}$ = average gamma-ray energy per disintegration in MeV/disintegration.

χ = radionuclide concentration (Ci/m).

Note the conservative assumption that the cloud is large enough to be considered infinite. The following example illustrates cloud dispersion with distance.

EXAMPLE

Given: An individual standing 500 meters downwind 2 hours after an accident that causes the release of 100 Curies per second of ^{133}Xe from a 50-meter stack.

Find: Maximum dose rate. Repeat for 2 kilometers downwind.

Solution: ^{133}Xe emits a beta with maximum energy of 0.346 MeV and a gamma of 0.081 MeV 37% of the time. $T_{\frac{1}{2}} = 5.3$ days; neglect decay.

From Figure 18-5-4, the maximum concentration at 500 meters from a 50-meter stack during the first 8 hours would be —

$$(\chi/Q)(Q) = (6.0 \times 10^{-5}\ \text{sec/m}^3)(100\ \text{Ci/sec})$$
$$= 6.0 \times 10^{-5}\ \text{Ci/m}^3.$$

Beta dose:

$$\bar{E}_{\beta} \cong \Sigma\ \text{max}/3 = 0.346/3 = 0.115\ \text{MeV/dis}$$

$${}_{\beta}D'_{\infty} = (0.23)(0.115)(6.0 \times 10^{-3})$$
$${}_{\beta}D'_{\infty} = 1.59 \times 10^{-4}\ \text{rad/second.}$$

Gamma dose:

$${}_{\gamma}D'_{\infty} = (0.25)(0.081)(0.37)(6.0 \times 10^{-3})$$
$${}_{\gamma}D'_{\infty} = 4.50 \times 10^{-5}\ \text{rad/second.}$$

Total dose = $1.59 \times 10^{-4} + 0.45 \times 10^{-4}$

Total dose = 2.04×10^{-4} rad/second, or
0.73 rad/hour.

At 2 kilometers:

$\chi/Q = 3.5 \times 10^{-5}$ sec/m^3

$${}_{\beta}D'_{\infty} = 0.23\ (0.115)(3.5 \times 10^{-5})(100)$$

$${}_{\beta}D'_{\infty} = 9.26 \times 10^{-5} \text{ rad/sec.}$$

$${}_{\gamma}D'_{\infty} = 0.25\ (0.081)(0.37)(3.5 \times 10^{-5})(100)$$

$${}_{\gamma}D'_{\infty} = 2.62 \times 10^{-5} \text{ rad/sec.}$$

Total dose = 0.43 rad/hr.

For a short-term, or "puff," release, the equations still can be used. If Q' is the total number of curies released, then –

$$\overline{\chi t} = (\chi/Q)(Q') \qquad \text{Eq. 18-5-4}$$

where:

$\overline{\chi t}$ = integrated concentration over time (curie/second/m^3).

This value is used in place of χ in Equations 18-5-5 and 18-5-6:

$${}_{\beta}D_{\infty} = 0.23\ \bar{E}_{\beta}\ \overline{\chi t} \qquad \text{Eq. 18-5-5}$$

$$\gamma^{D\infty} = 0.25\ \bar{E}_\gamma\ \overline{\chi t} \qquad \text{Eq. 18-5-6}$$

where:

$\beta^{D\infty}$ and $\gamma^{D\infty}$ = Total beta and gamma doses, respectively, received from the passing cloud.

Once again, such calculations must be augmented by sampling and should be used only for general conclusions on total population dose. Doses received from inhalation and ingestion usually will be of greater concern than cloud doses. An exception is the drastic situation, such as weapons fallout, in which radioactive particles deposit on the surface of the body in large amounts.

DISTRIBUTION IN WATER

Unfortunately, a generalized approach to dispersion of pollutants introduced into a body of water is impossible at the present state of knowledge. Physical mixing is highly dependent upon depth of water, type of bottom, shoreline configuration, tidal factors, depth at which the contaminant is introduced, and many other factors.

External dose to man originates primarily from submersion in contaminated swimming water in lakes, rivers, etc. Other activities, such as boating, may contribute up to half as much exposure as does swimming. A rough estimate of the dose rate due to complete submersion is given by Equation 18-5-7.

$$D_s = 2.13 \times 10^{-6}\ C\ (\bar{E}_\gamma + \frac{\bar{E}_\beta}{2}) \qquad \text{Eq. 18-5-7}$$

where:

D_s = whole-body dose rate in mrem/hr.
C = isotope concentration (ρCi/m^3).
$\bar{E}_\gamma$ and $\bar{E}_\beta$ = average gamma and beta energies per disintegration in MeV.

However, by far the most hazardous pathway from liquid releases is through ingestion of water or aquatic organisms, as explained in the next section.

EXAMPLE

Given: An individual swims for two hours in a lake that contains 10^{-6} μCi/ml of ^{137}Cs.

Find: Approximate dose.

Solution: ^{137}Cs emits a β^- with E_{max} of 1.17, 8% of the time, a β^- with E_{max} of 0.51 MeV (92%), and a γ at 0.66 MeV (82%).

$$C = 10^{-6}\ \mu\text{Ci/ml} \times \frac{10^6\ \rho\text{Ci}}{\mu\text{Ci}} \times \frac{10^6\ \text{ml}}{\text{m}^3}$$

$$C = 10^6\ \rho\text{Ci/m}^3.$$

$$E_\gamma = 0.66\ (0.82) = 0.541\ \text{MeV/dis.}$$

$$E_\beta = 1.17\ (0.08) + 0.51\ (0.92) = 0.563\ \text{MeV/dis.}$$

$$D_s = 2.13 \times 10^{-6}\ (10^6)[0.541 + \frac{0.563}{(2)(3)}]$$

$$D_s = 1.4\ \text{mrem/hr.}$$

Total dose = 2 x 1.4 = 2.8 mrem.

THE FOOD CHAIN

Whether accidental releases of radioactivity enter the environment via dispersion in air or by distribution in water systems, from that point the chemical characteristics of the element released determine its migratory path. They ultimately may affect man through a number of environmental paths.

Figure 18-5-10 depicts the generalized exposure pathways to man. The "food chain" is that portion of the internal pathway whereby radioactive materials are passed through air, water, soil, plants, and animals until they ultimately are ingested by humans. The chain must be carefully studied because the process can follow a number of avenues. Airborne contaminants may be inhaled, as well. Although not technically considered part of the food chain, the inhalation pathway must be just as closely examined.

As Figure 18-5-10 shows, internal exposures from liquid effluents are primarily the result of drinking-water contamination and consumption of marine or fresh-water organisms. The former requires that the radioactive materials find their way into water supplies by direct mixing, seepage, or precipitation. Attempts to calculate this type of dispersion quickly become far too involved for emergency conditions. Direct measurements of radio-concentrations in water supplies, therefore, are essential.

Some radionuclides move through the aquatic ecosystem by passing from small, simple oganisms to larger, more complex ones. Many of these life forms tend to retain certain trace elements to a greater degree than do others. The biological "concentration factor" (CF) for aquatic organisms can be defined as follows:

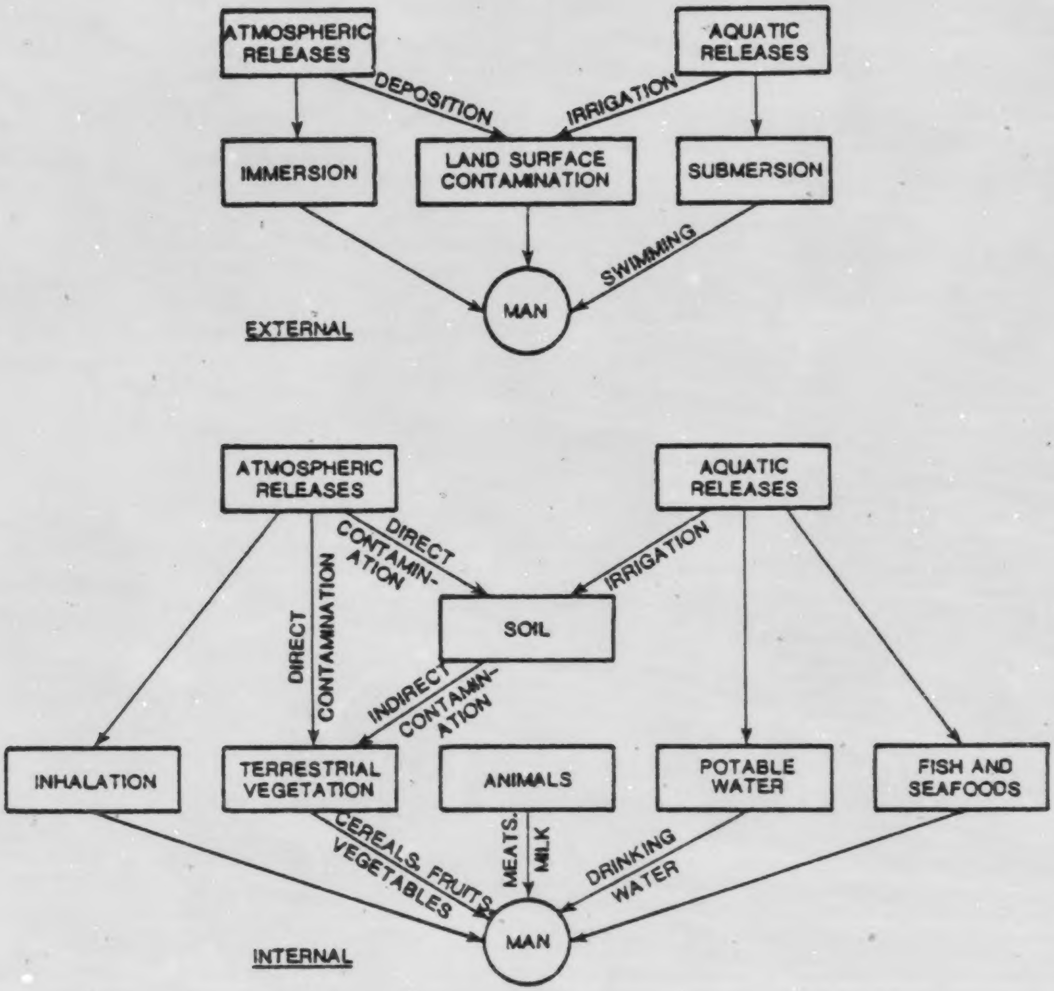
ATMOSPHERIC RELEASES
AQUATIC RELEASES
DEPOSITION
IRRIGATION
IMMERSION
LAND SURFACE CONTAMINATION
SUBMERSION
SWIMMING
MAN
EXTERNAL
ATMOSPHERIC RELEASES
AQUATIC RELEASES
DIRECT CONTAMINATION
DIRECT CONTAMINATION
IRRIGATION
SOIL
INDIRECT CONTAMINATION
INHALATION
TERRESTRIAL VEGETATION
ANIMALS
POTABLE WATER
FISH AND SEAFOODS
CEREALS, FRUITS, VEGETABLES
MEATS, MILK
DRINKING WATER
MAN
INTERNAL

Figure 18-5-10. Pathways for radiation exposure of man.

$$CF = \frac{\text{Concentration of element in the organism}}{\text{Concentration of element in the surrounding water}}$$

The CF provides useful infomration for long-term monitoring efforts. Samples of certain species with a high CF for a given element often can be analyzed with more accuracy than samples of the water itself. In addition, these samples provide data for post-emergency decision on restrictions to commercial or recreational fishing. Table 18-5-2 presents some concentration factors for edible aquatic organisms. Note that marine factors tend to be more uniform

TABLE 18-5-2

CONCENTRATION FACTORS FOR AQUATIC ORGANISMS (pCi/kg per pCi/l).

Element	Freshwater				Saltwater			
	Fish	Crustacea	Mollusks	Algae	Fish	Crustacea	Mollusks	Algae
H	0.9	0.9	0.9	0.9	1	1	1	1
Na	100	200	200	500	1	1	1	1
P	100000	20000	20000	500000	10000	10000	10000	100000
Cr	20	2000	2000	4000	100	1000	1000	1000
Mn	400	90000	90000	10000	3000	10000	50000	10000
Fe	100	3200	3200	1000	1000	4000	20000	5000
Co	50	200	200	200	100	10000	300	100
Ni	100	100	100	50	500	100	100	100
Rb	2000	1000	1000	1000	30	30	10	10
Sr	30	100	100	500	1	1	1	20
Y	25	1000	1000	5000	30	100	100	500
Zr	300	6.7	6.7	1000	30	100	100	1000
Nb	30000	100	100	800	100	200	200	100
Mo	10	10	10	1000	10	100	100	100
Tc	15	5	5	40	10	100	100	1000
Ru	10	300	300	2000	3	100	100	1000
Rh	10	300	300	200	10	100	100	100
Te	400	75	75	100	10	10	100	1000
I	15	5	5	40	20	100	100	10000
Cs	2000	100	100	500	30	30	10	10
Ba	4	200	200	500	3	3	3	100
La	25	1000	1000	5000	30	100	100	500
Ce	1	1000	1000	4000	30	100	100	500
Pr	25	1000	1000	5000	100	1000	1000	1000
Nd	25	1000	1000	5000	100	1000	1000	1000
W	1200	10	10	1200	10	10	100	100
U	2	60	60	0.5	10	10	10	5
Np	10	400	400	300	10	10	10	5

and lower than those for fresh water. This is because sea life is accustomed to an environment that contains larger amounts of mineral constituents and need not concentrate them as much to obtain the necessary quantities.

Radioactive materials present in soil will pass into plant root systems in the same manner as nonradioactive isotopes of that element as long as they are in the proper chemical (ionic) form. This includes elements that are not necessarily needed for normal metabolism. It may be assumed that if an element is present in the soil, it also will be found in the plant root system to at least some extent. Concentration factors can be defined for plants as well as for animals. Table 18-5-3 lists tendencies of various elements to concentrate in the first crop of plants grown after the element has been applied to the soil in a soluble form.

Radioactive substances may bypass the soil and more directly enter the food chain through "foliar deposition." In this process, the radionuclides are carried through the air and deposited on the surface of the plant, where they may be absorbed or remain as superficial contamination. This exposure path has been studied extensively in relation to fallout from nuclear weapons. It was discovered that many fission products found their way into the chain by this method as much as 90% of the time.

TABLE 18-5-3

RELATIVE CONCENTRATION OF ELEMENTS IN THE FIRST CROP PLANTS GROWN AFTER THE ELEMENTS HAVE BEEN APPLIED IN WATER-SOLUBLE FORM AND MIXED INTO SURFACE SOIL.

10-000 Strongly Concentrated	1-100 Slightly Concentrated	0.1-10 Not Concentrated	0.01-1 Slightly Excluded	<0.01 Strongly Excluded
K	Mg	Ba	Cs	Sc
Rb	Ca	Ra	Be	Y
N	Sr	Si	Fe	Zr
P	B	F	Ru	Ta
S	Se	I		W
Cl	Te	Co		Ce
Br	Mn	Ni		Pm
Na	Zn	Cu		Pb
Li	Mo			Pu
				Sb

Relative concentration factor $\frac{\text{ppm in dry plant material}}{\text{ppm in dry soil}}$.

The significance of foliar contamination varies with the growing season, type of land, structure of the foliage, and the plant's relation to the dietary habits of man. Longer-lived nuclides must be tracked through processes that exhibit possible delays of a year or more before consumption; for example, grain storage for flour production. However, for nuclides with half-lives on the order of several days or less, fairly rapid movement is required to reach man prior to decay.

Next to consumption of contaminated vegetation, the quickest food-type exposure route is through dairy products. This path is illustrated in Figure 18-5-11. Radioisotopes of iodine, cesium, and strontium are of special interest

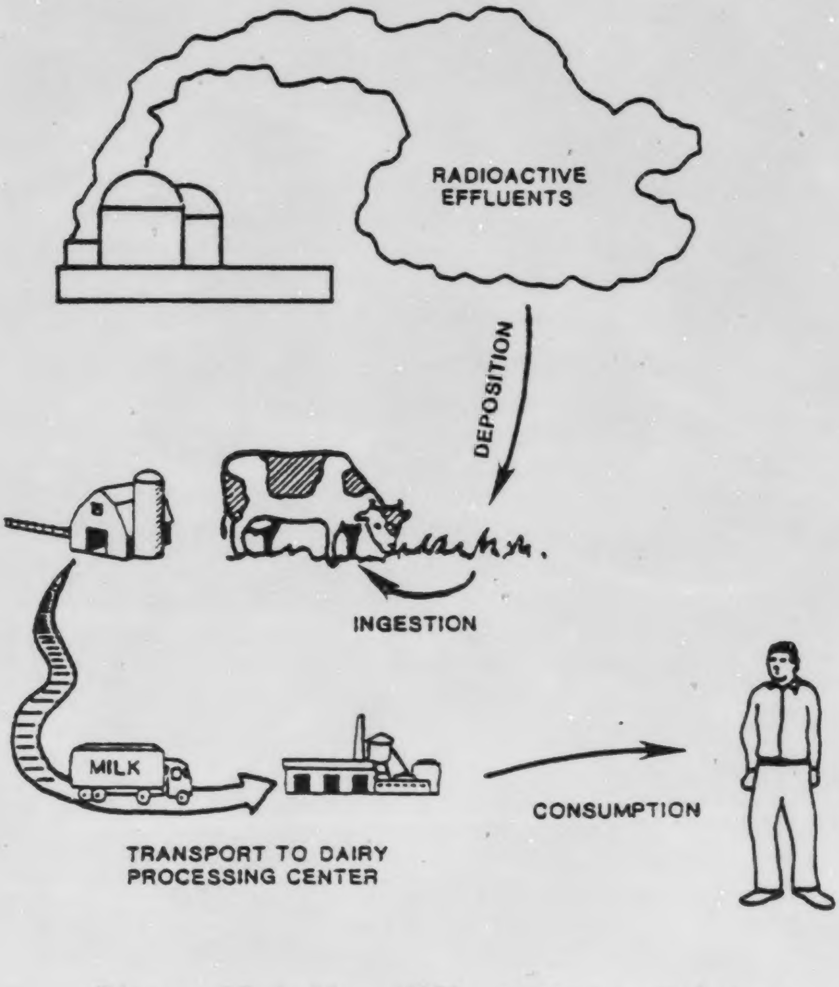
RADIOACTIVE
EFFLUENTS
DEPOSITION
INGESTION
MILK
TRANSPORT TO DAIRY
PROCESSING CENTER
CONSUMPTION

Figure 18-5-11. Milk exposure pathway.

because they can be concentrated in milk through an animal's grazing. The radionuclide ^{131}I, in particular, has a half-life of 8 days. This is sufficiently long for a significant fraction of the original quantity present in the milk to survive the processing-distribution cycle and to reach humans. Another isotope, ^{133}I ($T_{\frac{1}{2}}$ = 21 hours), also can cause problems if the milk is quickly consumed as might be the case rurally. The isotope ^{129}I has a half-life of 16 million years but is usually not present in significant quantities except under drastic conditions. The fission products ^{90}Sr ($T_{\frac{1}{2}}$ = 28 years) and ^{137}Cs ($T_{\frac{1}{2}}$ = 30 years) also can be significant milk contaminants.

Each element is transferred from the foliage to milk to a different extent. As an example, up to 1-2% of the iodine ingested during a day of grazing may find its way into each liter of a cow's milk. On the other hand, only a few tenths of a percent of strontium may reach the milk. Cesium lies somewhere between.

As might be expected, it is difficult to calculate the concentrations of radioactive materials in milk following pasture contaminations. Some reliable models are available for planning purposes; however, for an accurate estimate, there must be field study at the time and place of contamination. This is true not only for emergencies but also for controlled releases. A complete monitoring program must contain provisions for measurement of the concentrations of radioactive materials in local dairy products and for restriction of their distribution if necessary. Removal of radionuclides from foliage will be enhanced by weathering and drying of plants. Weathering and drying speed up the process somewhat over pure radioactive decay. Under average conditions, for example, iodine will be removed at the rate of about 5% per day in this manner alone.

INTERNAL EXPOSURE

Once a radioactive nuclide is internally deposited, the body's affinity for that particular element and chemical form becomes important. Radioactive particles or aerosols may become concentrated in body tissues or organs. Here their close proximity results in high dose rates from small amounts of activity, which would be considered insignificant if only present externally.

The "critical organ" is the organ in which a given radionuclide tends to accumulate and do the most damage. In some cases, the whole body becomes the critical organ. Table 18-5-4 lists a number of nuclides than can be of interest, together with their associated critical organs. The degree of harm done depends upon the radioactive properties of the isotope and the sensitivity of the organ.

Radioiodines, mentioned earlier, concentrate in the thyroid gland. The milk chain is the primary mode of entry for elemental, soluble iodine. The "critical receptor" usually is understood to be a young child because of a normally higher milk consumption and greater radiation sensitivity. Hypothyroidism, or even thyroid cancer, may result from large enough doses. Table 18-7-5 lists the dependence of thyroid dose upon age. If iodine is in the organic form of methyliodide, inhalation is the controlling intake path. An estimate of the average thyroid dose, D_T, from inhalation can be determined from Equation 18-5-8.

$$D_T = 330 \cdot Q' \text{ rem} \qquad \text{Eq. 18-5-8}$$

TABLE 18-5-4

PRINCIPAL PATHWAYS FOR RADIATION EXPOSURE FROM REACTOR EFFLUENTS

Radionuclide	Discharge Mode	Principal Exposure Pathways	Critical Organ
Radioiodine	Airborne		
		Air inhalation	Thyroid gland
		Grass-cow-milk	Thyroid gland
		Leafy vegetables	Thyroid gland
	Water	Drinking water	Thyroid gland
		Fish consumption	Thyroid gland
		Shellfish	Thyroid gland
Tritium	Airborne	Air inhalation and transpiration	Whole body
	Water	Drinking water	Whole body
		Food consumption	Whole body
Cesium	Airborne		
		Grass-cow-milk	Whole body
		Grass-meat	Whole body
		Inhalation	Whole body
	Water	Drinking water	Whole body
		Fish consumption	Whole body
Transition metals (Fe,Co,Ni,Zn,Mn)	Water	Drinking water	G.I. tract
		Shellfish consumption	G.I. tract
		Fish consumption	G.I. tract
	Airborne	Leafy vegetables	Bone
Strontium		Grass-cow-milk	Bone
		Grass-meat	Bone
		Inhalation	Bone
	Water	Drinking water	Bone
		Fish consumption	Bone
Plutonium	Airborne	Air inhalation	Lung
		Grass-cow-milk	Bone, liver
		Leafy vegetables	Bone, liver
	Water	Drinking water	Bone, liver
		Fish consumption	Bone, liver

TABLE 18-5-5

DEPENDENCE OF IODINE DOSE UPON AGE.

Age Group (years)	Age of "Typical" Individual (years)	Dose Intake Conversion Factor	
		^{131}I	^{133}I
		(mrem/pCi ingested)	
<1	0.5	2.0×10^{-2}	6.3×10^{-3}
1-9	4	1.6×10^{-2}	4.5×10^{-3}
10-19	14	3.1×10^{-3}	8.0×10^{-4}
>20	20	1.6×10^{-3}	3.9×10^{-4}

where:

Q' = total curie-seconds/m^3 of exposure to ^{131}I from Equation 18-5-4.

Another group of elements can be quite hazardous if ingested in radioactive form. These are alkaline-earth elements, which tend to be "bone seekers"; that is, they concentrate in the skeletal system. The foremost example is strontium in the form of ^{90}Sr, which tends to accompany calcium through the milk cycle due to the chemical similarity between the two. Large radiation doses to the bone and bone marrow may cause leukemia, anemia, or bone tumors.

Also of special concern are alpha-emitting nuclides. The very short range of alpha particles results in the deposition of a large amount of energy in a small volume — which is highly damaging. While some of these are bone-seekers such as radium (an alkaline earth), others behave quite differently. Uranium and plutonium are examples.

The former is difficult for the body to absorb and is quickly eliminated, so that the kidney becomes the organ of concern. Only long-term exposure is serious. However, plutonium may behave in a number of ways, depending upon its chemical form; and it is quite difficult to eliminate. For plutonium inhalation, the lung is of most concern; ingested plutonium, on the other hand, may deposit in the bone, in the liver, or even in the lymph nodes.

Other radionuclides present their own special hazards. Radioactive ^{3}H (tritium) is a unique problem, in that it travels through the body just as water does. Thus, it does not concentrate, but actually disperses itself in body tissues. Tritium can even enter the body directly through the skin, by a process known as "transpiration." Releases of several radionuclides that may have widely differing metabolic behavior can rapidly create some enormous environmental problems.

LIMITS ON RADIO-CONCENTRATIONS

To protect critical organs, "maximum permissible body burdens" (MPBB) have been determined. These are maximum amounts of each radionuclide (in μCi) allowed in the body constantly so that doses to the organs of interest are less than allowable values. The body burden of a given radionuclide may be measured by the radioactive counting of excreta, blood, tissue, or the entire body. This concept can be further extended into the environment by computation of "maximum permissible concentrations" (MPC) of nuclides in air and water. Taking into consideration the elimination rate of a given nuclide from the body, MPCs are calculated so that routine, daily uptake of such concentrations would not result in body burdens that exceed those allowable.

Every person working in radiation protection should be familiar with MPBB and MPC values for any radionuclide routinely present. These can be found in Title 10, Part 20 of the U.S. Code of Federal Regulations or similar state documents. Such limits normally are given for both restricted and unrestricted areas. Table 18-5-6 gives examples of MPCs

TABLE 18-5-6

CONCENTRATIONS IN AIR AND WATER ABOVE NATURAL BACKGROUND (μCi/ml).

Isotope		Restricted Areas		Restricted Areas	
		Air	Water	Air	Water
Chromium-51	S	1×10^{-5}	5×10^{-2}	4×10^{-7}	2×10^{-3}
	I	2×10^{-6}	5×10^{-2}	8×10^{-8}	2×10^{-3}
Cesium-137	S	6×10^{-8}	4×10^{-4}	2×10^{-9}	2×10^{-5}
	I	1×10^{-8}	1×10^{-3}	5×10^{-10}	4×10^{-5}
Tritium	S	5×10^{-6}	1×10^{-1}	2×10^{-7}	3×10^{-3}
	I	5×10^{-6}	1×10^{-1}	2×10^{-7}	3×10^{-3}
	Sub	2×10^{-3}	-	4×10^{-5}	-
Iodine-129	S	2×10^{-9}	1×10^{-5}	2×10^{-11}a	6×10^{-8}
	I	7×10^{-8}	6×10^{-3}	2×10^{-9}a	2×10^{-4}
Iodine-131	S	9×10^{-9}	6×10^{-5}	1×10^{-10}a	3×10^{-7}
	I	3×10^{-7}	2×10^{-3}	1×10^{-8}a	6×10^{-5}
Iodine-133	S	3×10^{-8}	2×10^{-4}	4×10^{-10}a	1×10^{-6}
	I	2×10^{-7}	1×10^{-3}	7×10^{-9}a	4×10^{-5}
Plutonium-239	S	2×10^{-12}	1×10^{-4}	6×10^{-14}	5×10^{-6}
	I	4×10^{-11}	8×10^{-4}	1×10^{-12}	3×10^{-5}
Strontium-90	S	1×10^{-9}	1×10^{-5}	3×10^{-11}	3×10^{-7}
	I	5×10^{-9}	1×10^{-3}	2×10^{-10}	4×10^{-5}
Xenon-133	Sub	1×10^{-5}	-	3×10^{-7}	-
Unkown T 1/2< 2 hrs		1×10^{-6}	-	3×10^{-8}	-
T 1/2> 2 hrs		3×10^{-9}	9×10^{-5}	1×10^{-10}	3×10^{-6}

[a] For nuclear power plants, the value must be multiplied by 1/3.

S = Soluble I = Insoluble Sub = Submersion in semi-infinite cloud.

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found in federal regulations. Adherence to these values will provide sufficient safety in general. However, it is the job of health physics personnel to keep radioactivity levels in the environment as low as reasonably achievable.

EMERGENCY ACTION LEVELS

During a radiological emergency involving a release to the unrestricted environment, protective actions may have to be initiated. The facility emergency plan will describe actions to be taken in the event that certain prespecified instrument readings, measured radionuclide concentrations, or calculated doses or dose rates are reached or projected. These values may be called "radiological action levels." They are part of the many plant emergency-action levels that cover other types of hazards as well.

There are three immediate responses that may be considered – temporary isolation, elemental therapy, and evacuation. Recommended action levels are listed in Table 18-5-7. The act of staying indoors provides protection from direct deposition and inhalation for low concentrations. When iodine levels are significant, the thyroid may be "blocked" by the taking of potassium iodide. This procedure fills the thyroid with stable iodine, causing it to reject most of the radioiodine, which then is eliminated. Evacuation is a last resort, but it may be necessary. The hazards associated with the evacuation of large populations may be greater than the radiation hazard itself.

TABLE 18-5-7

RECOMMENDED EMERGENCY ACTION LEVELS BASED ON THE DOSE IN THE OPEN AIR FROM EXTERNAL IRRADIATION AND INHALATION OF RADIONUCLIDES.

		Recommended Action		
Range of Risk	Expected Dose in Open Air (mrem)	Warning to Stay in House and Close Doors and Windows[b]	Distribution of Iodide Tablets[c]	Evacuation[d]
Irradiation of Thyroid by Inhaled Iodines				
I	<25	Useful	Not necessary	No
II	25-500	Necessary	Useful; necessary when > 100 rem	Not necessary
III	>500	Necessary until evacuation	Necessary even when evacuated	Useful; necessary when > 1000 rem
Irradiation of the Whole Body by External Radiation and Inhaled Radionuclides				
I	<25	Useful	Not applicable	No
II	25-100	Necessary	Not applicable	Useful
III	>100	Necessary until evacuation	Not applicable	Necessary

Action levels for long-term time frames also may be established. Such measures as confiscation of milk, quarantine of pasture or farm lands, or use of bottled water may be required. When such decisions are made, the economic impact must be weighed against the measure contemplated. For localized, limited-quantity releases that affect only small farms, for example, the above types of actions may be initiated if MPC values are set with continual uptake in mind. Higher values of action levels should be used if major economic impact would occur, such as with large dairy or produce operations. Table 18-5-8 lists some possible radiological action levels for food chain protective measures.

TABLE 18-5-8

SAMPLE RADIOLOGICAL ACTION LEVELS FOR
ISOTOPE CONCENTRATIONS.

Isotope	Action Level for Intake Restrictions
Iodine-131	2×10^{-5} μCi/ml (water or milk)
	1.3 μCi/m^2 (pasture)
Strontium-90	1×10^{-6} μCi/ml (water or milk)
	1×10^{-1} μCi/m^2 (pasture)
Cesium-137	1×10^{-4} μCi/ml (water or milk)
	22 μCi/m^2 (pasture)

The steps to be taken in the control of radiological hazards that result from an accident will depend largely upon the circumstances at the time of the emergency. The guides presented here always must be employed with judgment and tailored to the specific facility and surrounding environment. If major disruption of public activities occurs, much animosity toward the source facility can be expected. However, the public's welfare must be the foremost concern. Emergency action levels should be designed only under this philosophy.

MONITORING SYSTEMS

"Environmental surveillance" can be defined as "a continuous program for radiation surveys of the area around a nuclear facility." However, in reality, it encompasses much more and must begin with the monitoring and control of radiological hazards within a facility. This not only will protect employees, but also will provide a warning system that minimizes the possibility of radioactive releases that could adversely affect public health and safety.

Monitoring instrumentation must be placed strategically throughout the facility in order that dangerous situations will be detected quickly. Such systems may activate alarms that call for manual emergency action or may themselves initiate automatic measures. An example of the latter is the interfacing of a ventilation exhaust system with a particulate monitor that shuts down air flow if necessary to prevent an abnormal release to the environment. Personnel actions will be governed by predetermined alarm levels. These actions involve preventive measures, as well as those aimed at minimizing unwarranted exposures or effluent releases during emergencies.

Radiological monitoring instruments should include a minimum of the following systems. These systems provide the necessary information for routine operations and emergency conditions.

AREA RADIATION MONITORS

In a facility, this monitoring system should contain a sufficient number of channels to allow the placement of a detector in each area in which radioactive materials are processed or radiation levels in support equipment could vary significantly. An area radiation monitor should be placed adjacent to a resin-bead treatment system for reactor cooling water, for example; and the systems should be equipped with alarm and readout capabilities at the detector location. Additionally, remote readouts and both audio and visual alarms should be located in the facility control room or other established control points. The detectors themselves are ionization chambers or other properly calibrated radiation detectors that have a wide range of sensitivity, from normal operating levels up to several thousand rads/hr. These monitors, especially, must be placed at locations at which accidents can happen while personnel may be present. Area radiation monitors not only alert those in the area of dangerous levels of radiation, but also provide a system by which operations personnel can assess the radiological conditions at important locations around the facility from a remote area removed from the radiation hazard.

AIRBORNE PARTICULATE MONITORS

These radiation monitoring instruments are designed to measure the concentration of radioactive particulate matter in the air by filtering out the particulates (collecting them on some filter media) and counting the radioactivity with a Geiger-Müeller or gas proportional counter. Examples are provided in Figures 18-5-12 and 18-5-13. They may be either continuous, or fixed, filtering systems. In a continuous filtering system, the filter media continuously moves across a collection path at a known and calibrated rate of travel.

The detector and the particulate collection system must be enclosed within a shielded assembly to reduce back-

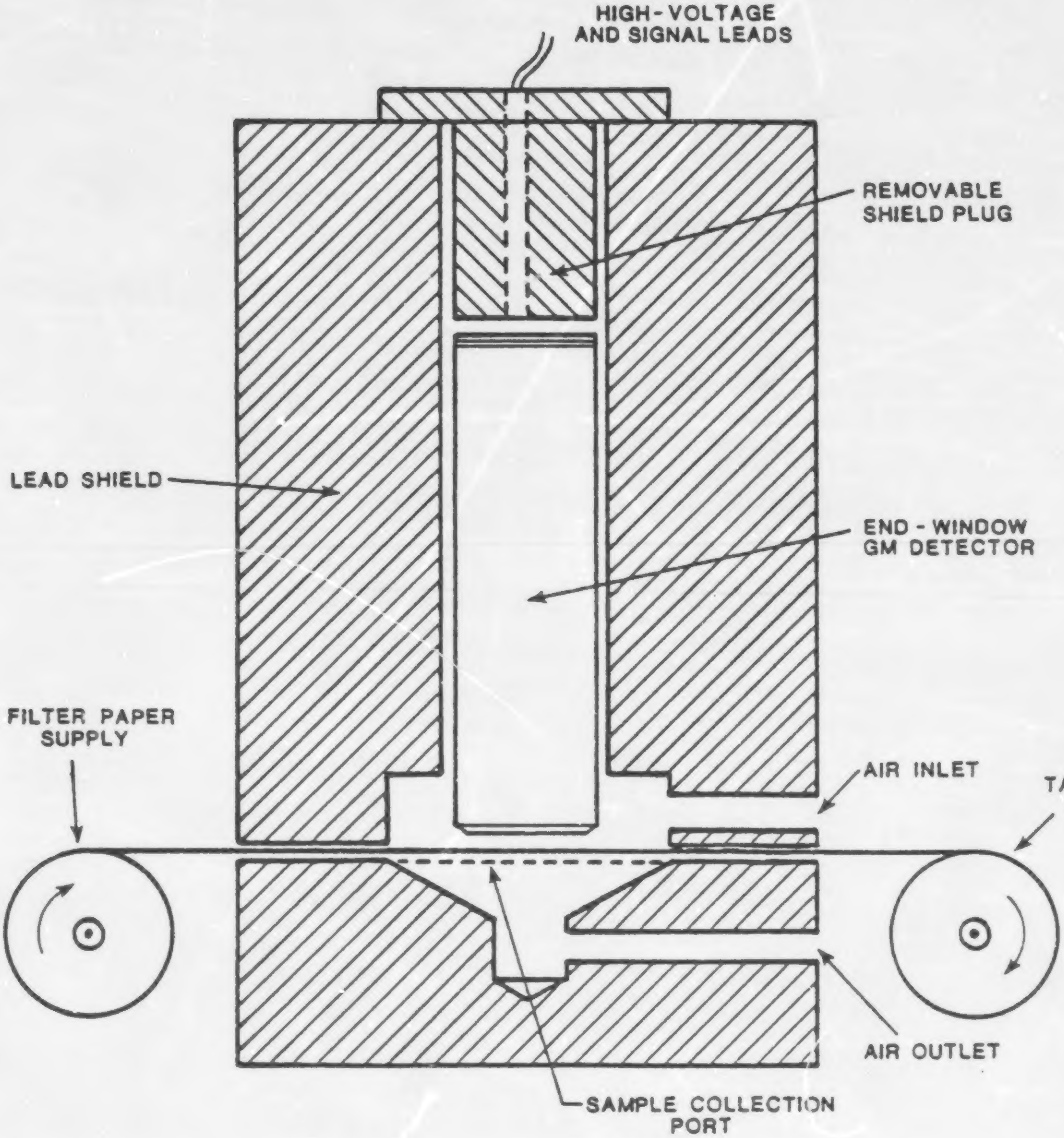
HIGH-VOLTAGE AND SIGNAL LEADS
REMOVABLE SHIELD PLUG
LEAD SHIELD
END-WINDOW GM DETECTOR
FILTER PAPER SUPPLY
AIR INLET
TAKE-UP REEL
AIR OUTLET
SAMPLE COLLECTION PORT

Figure 18-5-12. Moving air filter arrangement.

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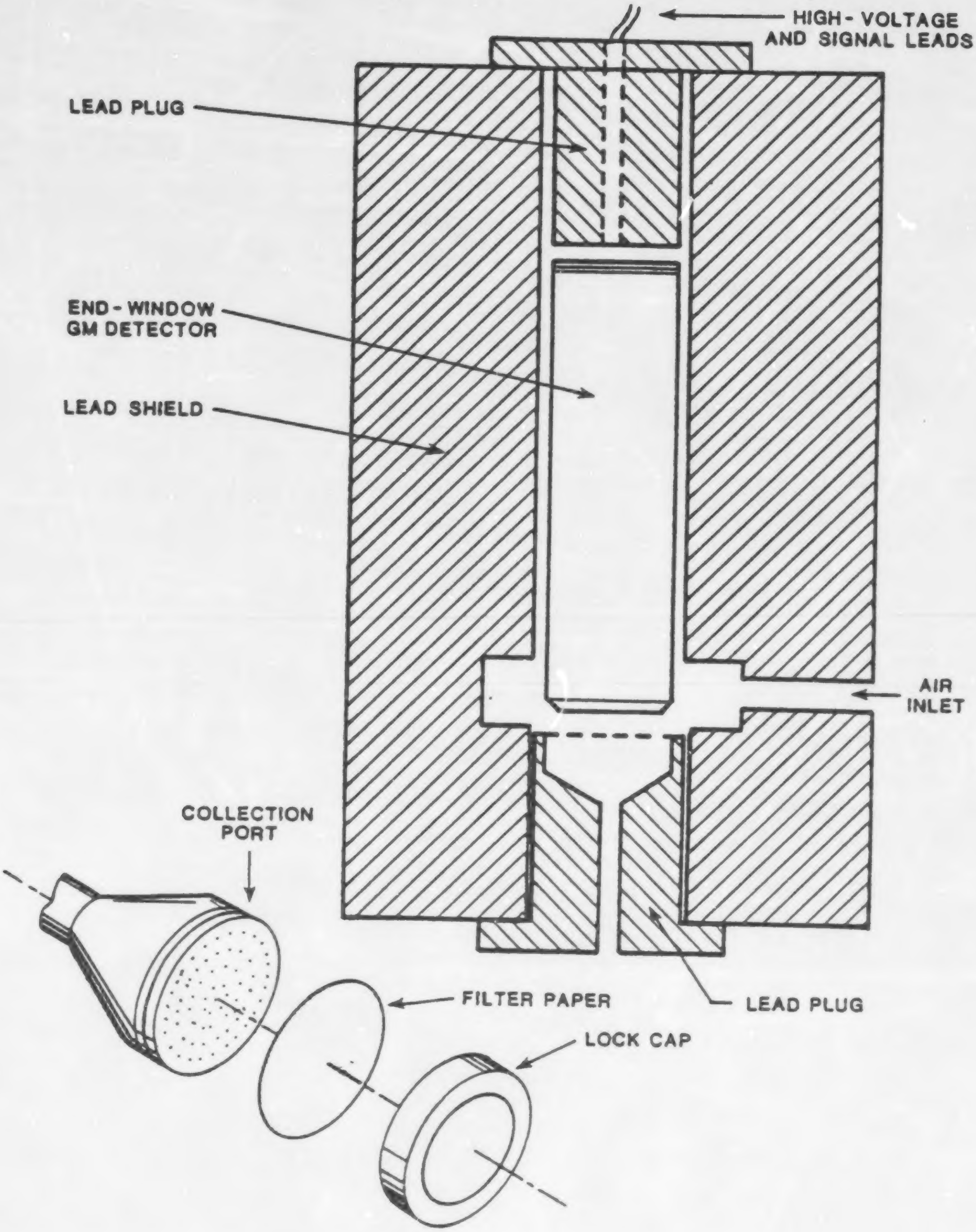
HIGH-VOLTAGE AND SIGNAL LEADS
LEAD PLUG
END-WINDOW GM DETECTOR
LEAD SHIELD
AIR INLET
COLLECTION PORT
FILTER PAPER
LEAD PLUG
LOCK CAP

Figure 18-5-13. Fixed air filter arrangement.

ground radiations to a level at which minimum detectable activities are only a small fraction of the permissible limits on airborne activities. This allows for the measurement of low concentrations, while providing, at the same time, the capability to alert personnel of an impending hazard from high levels of airborne radioactive particulates. The monitors should be equipped with alarms and direct readouts at the sampling location to alert personnel in that area. Also, they should include remote readouts, graphic recorders, and both audio and visual alarms located at established control points.

Properly positioned and calibrated monitors for airborne particulate provide operators and supervisory personnel with valuable information for assessing the radiological conditions at strategic locations and under both normal and accident conditions. If an accident involves the release of large amounts of beta or alpha emitters without significant levels of gamma radiation, an area radiation monitor would not detect that release. However, a properly designed air monitor not only will detect the situation, but also will provide data on both isotope concentrations and total release of radionuclides to the environment.

GASEOUS RADIOACTIVITY MONITORS

The monitoring of gaseous radioactivity is accomplished by collection of a gas sample of sufficient volume to accumulate the amount of radioactivity required for accurate measurements. The gas-sampling vessel should be designed in such a manner as to surround the radiation detector for maximum operating efficiency of the system. Figure 18-5-14 is a schematic of a gas monitor.

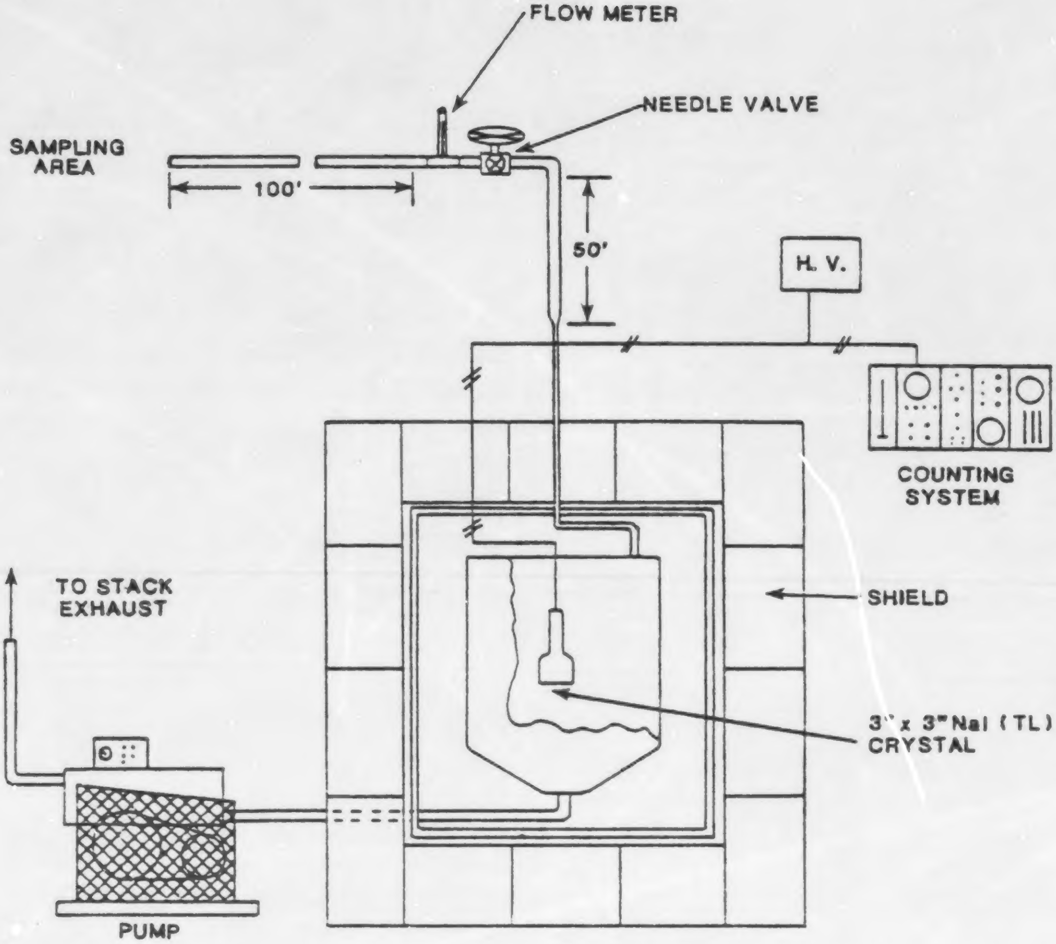
FLOW METER
NEEDLE VALVE
SAMPLING AREA
100'
50'
H. V.
COUNTING SYSTEM
TO STACK EXHAUST
SHIELD
3" x 3" NaI (TL) CRYSTAL
PUMP

Figure 18-5-14. Gaseous radiation monitor.

The most common detectors used for measuring concentrations of gaseous radionuclides in the air are scintillation counters sensitive to beta and gamma radiation. Like other monitors, they should be equipped with the required alarms, readouts and graphic recorders at control points. Also, these monitors provide data that are immediately pertinent to the safety of the environment because gaseous radionuclides are not collected (filtered out) in standard filtering systems unless they include specially designed gas traps.

FACILITY ALARM SYSTEMS

These alarms, although normally activated by operators or supervisory personnel, also may be activated automatically by a signal initiated at a preset level on a monitoring system. The facility alarm system is used to alert personnel to hazardous conditions and to trigger evacuation to previously established assembly areas that should remain free of contamination or other hazards.

EFFLUENT MONITORS

"Effluent monitors" are so designated by their use; and they consist of any one or a combination of the monitoring systems previously described. They are placed in the effluent streams of airborne and liquid effluents from the facility. Their purpose is to measure concentrations and total quantity of radioactive materials released to the environment.

One can now see that environmental surveillance really begins with the monitoring, control, and documentation of activities within the facility that could affect the environs. The previous definition of environmental surveillance now can be expanded: It is defined more fully as the measurement of those levels of ionizing radiation and radionuclide concentrations in the environment required for an accurate assessment of man's exposure to both natural and man-made sources of radiation. This simple statement may be quite complex when one considers the requirements for ascertaining compliance with government regulations, the movement and retention of man-made radionuclides in environmental media, and the composition and contribution to man's exposure from naturally-occurring radiations. The next step is to establish a comprehensive environmental sampling program to gather the information required for a valid surveillance program.

ENVIRONMENTAL SURVEY

Sampling of the plant and animal life in the region surrounding a nuclear facility is the only sure way to ascertain the impact of releases to the environment. The data obtained are not merely numbers to be reported and filed. They must be related to the actual doses that individuals may receive as a result of the activities conducted by a nuclear facility, in order that a meaningful cost benefit analysis can be done.

Environmental survey programs are classified, or defined, by timing; that is, by establishment of the program in three major categories: (1) pre-operation, (2) initial operation or startup, and (3) routine, or post, operations of the facility. The pre-operational phase of the program is used to establish baseline data on natural radiation background of the facility environs, as mentioned earlier in this module. This survey should include the determination of reasonable fluctuations of background radiation associated with temperature, rainfall, and other meteorological data such as wind speed and direction. The pre-operational surveys are conducted during the period preceding startup of the facility, preferably beginning at least one year before any site-clearing or construction of the plant begins. They include the collection and analysis of samples representative of the flora and fauna of the region. Preoperational data is collected for air; water; and animal products, including milk. Other samples, such as cheese and eggs, should be considered if they are locally produced and processed. Most of the information gathered during this phase will be needed for regulatory requirements and possible future legal purposes; therefore, the data must be as complete and as valid as possible. Additionally, time should be provided for the training of personnel and the testing of all analytical equipment and procedures.

The initial operation phase usually spans the first nine to 12 months of routine operations of the facility. The data from sample analyses during this phase is of particular importance to the identification of any unexpected occurrences or weaknesses in the survey program. Data are evaluated and compared with predicted levels. The actual impact on the environment from plant operations then can be determined. The results from this phase are used to devise the final survey program for the facility. The program will provide a continuous record of effluent releases, their dispersion, and their relationship to dose assessment.

The routine phase of the program is based upon the early experience and the results obtained during the preoperational and initial phases of the program. The program should be well established by this time to ensure the ability to collect the samples required for maintaining an effective level of confidence that normal releases are less than allowable and that there is sufficient capability to respond to emergencies or unexpected occurrences.

The environmental survey program should be continually evaluated and amended as necessary to meet regulatory requirements. (Table 18-5-9 lists some basic aspects of a sampling program.) Combined with designed-in safety, this ensures the public that their increased exposure from facility releases will be kept AS LOW AS REASONABLY ACHIEVABLE.

TABLE 18-5-9

SAMPLE OFF-SITE SURVEILLANCE PROGRAM.

Operation or Sample Type	Approximate Number of Samples and Their Locations	Collection Frequency	Analysis Type and Frequency
Air particulates	1 sample from the 3 locations of the highest offsite ground level concentrations	Continuous collection – filter change as required	Gross long-lived β at filter change^b
	1 sample from 1-3 communities within a 10-mile radius of the facility		Composite for gamma isotopic analysis and radiostrontium analysis quarterly
	1 sample from a location greater than a 20-mile radius in the least prevalent annual wind direction		
Air iodine	Same sites as for air particulates	Continuous collection-canister changes as required	Analyze weekly unless absence of radioiodine can be demonstrated
Direct radiation	2 or more dosimeters placed at each of the locations of the air particulate samples which are located at the 3 highest offsite ground level concentrations	Quarterly	Gamma dose quarterly
	2 or more dosimeters placed at each of 3 other locations for which the highest annual offsite dose at ground level is predicted		

	2 or more dosimeters placed at each of 1-3 communities within a 10-mile radius of the facility 2 or more dosimeters placed at a location greater than a 20-mile radius in the least prevalent annual wind direction		
Surface water	1 upstream 1 dowstream after dilution (e.g., 1 mile)	Monthly (Record status of discharge operations at time of sampling)	Gross β, gamma isotopic analysis monthly. Composite for tritium and radiostrontium analysis quarterly
Ground water	1 or 2 from sources most likely to be affected	Quarterly	Gross β, gamma isotopic analysis and tritium quarterly
Drinking water	Any supplies obtained within 10 miles of the facility which could be affected by its discharges or the first supply within 100 miles if none exists within 10 miles	Continuous proportional samples	Gross β, gamma isotopic analysis monthly. Composite for tritium and radiostrontium analysis quarterly
Sediment, benthic organisms and aquatic plants	1 directly downstream of outfall 1 upstream of outfall 1 at dam site downstream or in impoundments	Semiannually	Gamma isotopic analysis semiannually
Milk	1 sample at nearest off-site dairy farm in the prevailing downwind direction 1 sample of milk from local dairy representative of milkshed for the area	Monthly	Gamma isotopic analysis and radiostrontium analysis monthly
Fish and shellfish	1 of each of principal edible types from vicinity of outfall 1 of each of the sample types from area not influenced by the discharges	Semiannually	Gamma isotopic analysis semiannually on edible portions
Fruits and vegetables	1 each of principal food products grown near the point of maximum predicted annual ground concentration from stack releases and from any area which is irrigated by water in which liquid plant wastes have been discharged	Annually (at harvest)	Gamma isotopic analysis annually on edible portions

	1 each of the same foods grown at greater than 20 miles distance in the least prevalent wind direction		
Meat and poultry	Meat, poultry, and eggs from animals fed on crops grown within 10 miles of the facility at the prevailing downwind direction or where drinking water is supplied from a downstream source	Annually during or immediately following grazing season	Gamma isotopic analysis annually on edible portions
Quality control	Samples as required for accurate sampling and analysis		Minimum frequency – annually

EXERCISES

1. For each of the ten classes of information required for an environmental impact appraisal, contrast the data for a radioisotope processing plant on the outskirts of an inland metropolitan area and a nuclear power plant on the Mississippi River.
2. Calculate χ 2 kilometers downwind and 150 meters crosswind 2 hours after the beginning of a continuous release of 100 Ci/sec of ^{85}Kr. (Use Equation 18-5-1.) Also calculate χ from the upper limit curves in Figure 18-5-4, and compare the results. It is a cloudy night with a constant wind speed of 2 m/sec. Stack height is 75 meters. Neglect decay.
3. Calculate the maximum potential whole-body (gamma) and skin (beta) doses to an onlooker standing at a point 300 meters from a transporation accident in which

60 curies of ^{38}Cl were released five minutes previously. Chlorine-38 emits a beta with E_{max} = 4.91 MeV and gammas of 1.60 MeV (38%) and 2.17 MeV (54%). $T_{\frac{1}{2}}$ = 37 min. (Hint: Use Figure 18-5-8a.)

4. An abnormally high level of Cesium-137 is measured in the lake and soil near a plant. Describe methods of confirming this analysis.
5. Discuss the particular food chain problems that would be associated with a radioactive release in your area.
6. Why are isotopes that have an associated critical organ of more concern than inert gases?
7. Describe some general types of action levels that may be used at a plutonium processing plant.
8. The gas monitor at a research reactor needs to be calibrated in order that the count rate that corresponds to MPC for Argon-41 will be known. How might this be done? (Hint: Use the reactor for assistance.)
9. Discuss the three general types of emergency public protective actions for radiological releases to the environment.

MATERIALS

Reference materials on properties of radionuclides.

PROCEDURES

An accident occurs in which the following release rates are determined from a 125-meter stack:

Isotope	Release Rate
Xe-133	1000 Ci/sec
Kr-85	700 Ci/sec
I-131	25 Ci/sec

The Operations Manager says that this situation may continue for a day.

In addition, an accidental release of 10,000 gal of water that contains unknown fission-product activity was made into the river next to the site. There are several small dairy farms in the area and a small town of 1,000 people about 3 km downstream. A major metropolitan area of 100,000 people is located 10 miles away. If you were Manager of Health Physics at the site, describe your actions and recommendations under these conditions. Use any outside materials needed to aid in analysis.

DATA TABLE

None.

REFERENCE MATERIALS

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USNRC. Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants. Reg. Guide 1.145. Washington, DC: U.S. Government Printing Office, 1979.

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TEST

1. Describe the major sources of natural background radiation today.

2. List 5 types of data needed for a pre-operational environmental impact appraisal.

3. Calculate the concentration of Kr-85m 2 km directly downwind from a plant that is releasing 1500 Ci/minute.

Given: $T_{1/2}$ = 4.48 hr.
$\sigma_y = 1.5 \times 10^2$ m
$\sigma_z = 1.2 \times 10^2$ m
Wind speed = 6 km/sec
Stack height = 130 meters

Use:

$$\chi(x,y) = \frac{Q}{\pi \sigma_y \sigma_z \bar{u}} \exp - \left[\frac{y^2}{2\sigma_y^2} + \frac{h^2}{2\sigma_z^2} + \lambda t\right]$$

4. What is the total dose received by an individual who stands for 10 minutes in a cloud of Xe-133 that has a concentration of 1×10^{-2} Ci/m^3?

Given: E_β max = 0.346 MeV, E_γ = 0.81 MeV @ 37%

Use: ${}_\beta D'_\infty = 0.23\ \bar{E}_\beta\ \overline{\chi t}$; ${}_\gamma D'_\infty = 0.25\ \bar{E}_\gamma\ \overline{\chi t}$

5. What are the two principal ways by which aquatic radioactive releases can affect man?

6. Sketch the milk food chain.

7. Briefly describe the ways by which radioisotopes may enter the food chain via the atmosphere.

8. List the three isotopes of most concern in dairy product contamination.

9. What are the critical organs for the following radioactive isotopes?
   a. Iodines.

   b. Uranium.

   c. Strontium.

   d. Plutonium.

10. Why is tritium a particular problem if it enters the environment?

11. Briefly discuss the concept of MPC, and give the values for I-133 in restricted areas in air and water.

12. What is the action level (rem) for which evacuation is necessary for –

    a. External exposure.

    b. Thyroid exposure.

13. List three major types of monitoring systems.

14. Define the following terms:
    a. Natural background.

    b. Diffusion factor.

    c. Food chain.

    d. Concentration factor.

    e. Foliar deposition.

    f. Critical organ.

    g. Bone seeker.

    h. Transpiration.

    i. Maximum permissible concentrations.

    j. Maximum permissible body burdens.

k. Radiological action levels.

l. Environmental surveillance.

15. Briefly discuss the three phases of an environmental sampling program.

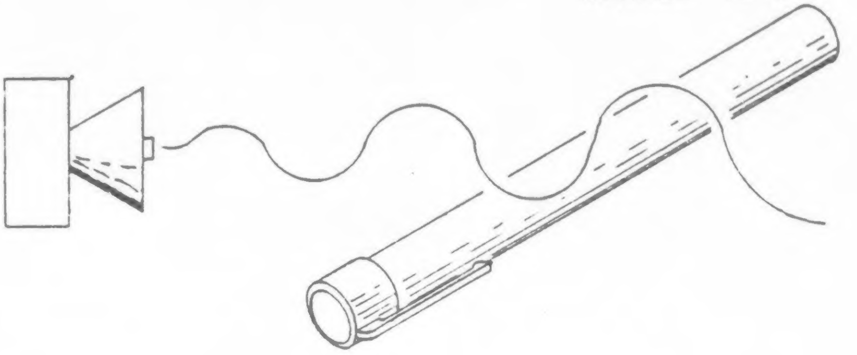
NUCLEAR TECHNOLOGY

MODULE 18-6

EMERGENCY PLANNING FOR NUCLEAR FACILITIES

RADIOLOGICAL
EMERGENCIES

COURSE 18



CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

COURSE 18 RADIOLOGICAL EMERGENCIES

Module 18-1	General Procedure for Radiological Emergencies
Module 18-2	Emergency Equipment for Nuclear Facilities
Module 18-3	Surface Contamination – Decontamination
Module 18-4	Criticality Control
Module 18-5	Control of Radiological Hazards
⇨ Module 18-6	Emergency Planning for Nuclear Facilities
Module 18-7	Emergency Drills for Nuclear Facilities

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INTRODUCTION

Many different plans have been made and executed in almost every field of human activity. Some plans are made to ensure convenience; others, to secure and preserve safety or even life itself. Behind every successful business, government, or military venture, there must be an extensive plan or set of plans.

This module describes the content and preparation of a radiological emergency plan. Also included are discussions of training and post-emergency activities.

An emergency is a condition that calls for immediate action beyond the scope of normal operating procedures to avoid or mitigate the consequences of an accident. When dealing with hazardous substances, it is only common sense for the responsible personnel to plan for emergencies. This is especially true of radioactive materials. Each nuclear facility is required by law to develop an emergency plan, with the protection of the health and safety of both the general public and nuclear workers as a goal.

MODULE PREREQUISITES

The student should have completed Course 1, "Radiation Physics"; Course 2, "Radiation Protection I"; Course 11, "Radiation Detection and Measurement"; and Course 17, "Radiation Protection II". All other modules in this Course are required for a comprehensive understanding of emergency planning.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Describe the reasons for, and general approach to, emergency planning at nuclear facilities.
2. Discuss the actions and responsibilities of various emergency groups within the facility.
3. List at least five off-site agencies that may be needed for support during emergencies; describe the responsibilities of each.
4. Generally outline the principles of on-site and off-site contamination control.
5. List six pieces of emergency equipment that should be available at the facility.
6. Briefly discuss the contents of an EAS kit.
7. Describe types and frequency of emergency training activities, including exercises.
8. Tour a nuclear facility, making a list of (a) potential problem areas during an emergency and (b) necessary equipment and its location.
9. Define the foloowing terms:
    - Emergency plan.
    - Emergency director.
    - Action levels.
    - Site emergency.
    - General emergency.
    - Assessment actions.
    - Protective actions.
    - Emergency operations center.
    - Emergency planning zone.
    - Exclusion area.
    - Walk-through exercise.
10. Outline post-accident activities following a nuclear accident.

On March 28, 1979, a series of human and mechanical failures at the Three Mile Island Nuclear Power Plant led to several unintentional releases of radioactive gases from the facility. Although there were no injuries or dangerous exposures, the emergency reaction of the utility and government agencies left much to be desired. As a result of Three Mile Island, there is a renewed emphasis on pre-planning for emergencies at all facilities. An emergency plan is a set of integrated, written procedures designed to minimize the probability and consequences of an accident.

The plan must describe the actions to be taken by facility personnel and off-site groups under various generalized types of circumstances. Because operations ranging in size from small radiochemical laboratories to large power reactors require response plans, a broad approach to emergency planning must encompass all types of facilities. By starting with general guidelines and adding the necessary procedures for the specific operation and environment under consideration, planners can develop an effective emergency plan.

TYPES OF EMERGENCIES

The three general classifications of radiation emergencies are –

- Releases of liquids, gases, or particulates.
- Lack or loss of shielding.
- Criticality accidents.

Fortunately, there have been only a few such accidents of any significance during the development of nuclear technology. In those that have occurred, carelessness in the conduction of routine activities usually was the cause. Familiarity often leads to violations or short-cuts of procedures; however, even such relatively minor operational changes may introduce a significant increase in injury potential without being recognized. There are almost no cases of accidents caused solely by failure to identify a hazard and to establish procedures for personnel to follow.

Whether an accident is caused by human eror, equipment malfunction, or inadequate design, the reasons for the incident usually are of secondary concern to its consequences when an emergency plan is prepared. This is especially true of off-site emergency control. An emergency action plan is an emergency plan that covers the immediate response to an accident and short-term, post-accident activities. Of course, consideration of potential accidents must be included in site selection and facility designs, as well. The intent of the information presented in this module is to allow the preparation of a comprehensive emergency action plan, given a fixed location and design.

PRINCIPLES OF EMERGENCY PLANNING

The proper implementation of the action plan will bring the necessary efficiency to what otherwise would be a very disorganized situation. Besides reducing the probability of surprises, the act of planning ahead also decreases the likelihood of timid or foolhardy responses, either of which could be equally as devastating as no response at all. The goal of an emergency plan is the minimum loss of people and property with a minimum effort. Formulation of a method of achieving this goal involves accomplishing some general objectives.

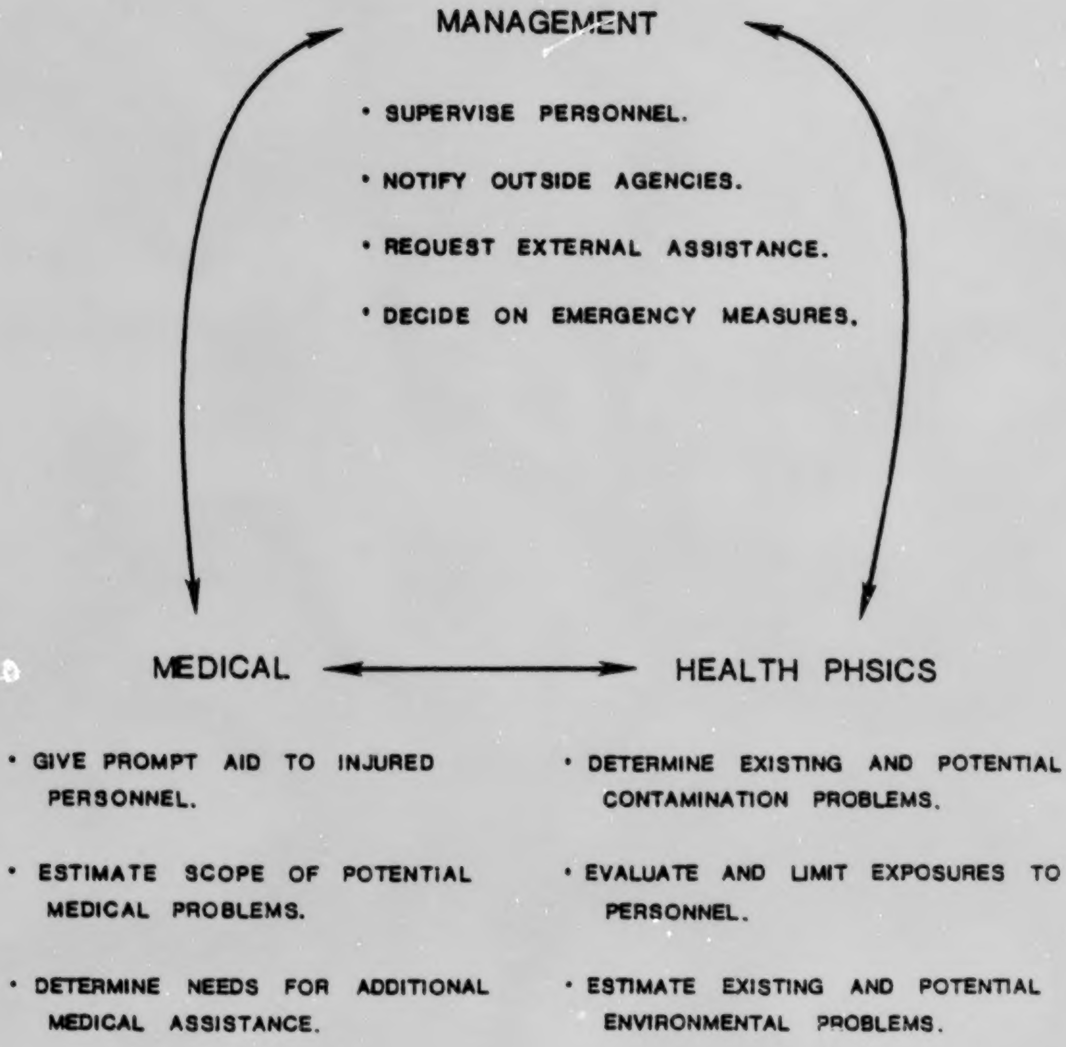
Table 18-6-1 describes the various broad objectives of a plan. The attainment of these objectives requires written procedures, cooperation backed by management support, routine testing and drills, and availability of the necessary equipment. Available emergency measures must be thoroughly explained to personnel, but every situation will require some degree of judgment. This should be pointed out where appropriate.

TABLE 18-6-1. OBJECTIVES OF EMERGENCY ACTION PLANS.

Objective	Description
Organization	To integrate all necessary personnel and agencies into an emergency team.
Definition	To develop a clear understanding of each group's responsibilities under various circumstances.
Participation	To ensure active cooperation of responsible agencies without dependence upon specific individuals who may not be available.
Preparation	To arrange for emergency equipment, assessment capabilities, and personnel training in order that the plan can be effective if needed.
Notification	To provide for alarm systems and communications networks needed for warning, problem identification, and initiation of the plan.
Direction	To establish control centers and scope of individual authority in order that there is no question about who is in charge.

There are three main areas of responsibility during emergencies. The are management, medical, and health services. These groups must interact closely with one another. Figure 18-6-1 illustrates the various responsibilities of each and their relationship. A separate individual should be clearly in charge of each group, and management should make ultimate decisions for overall actions.

Several major phases can be identified in the development of an emergency plan. Required steps include creation of an organization, determination of potential hazards, formulation of action plans, writing of procedures, training of personnel, testing of the plan, and maintenance of proficiency in implementing the plan via drills and periodic re-evaluation. The result is a comprehensive document, which, when combined with judgment, provides the means necessary effectively to cope with emergencies.



MANAGEMENT

- SUPERVISE PERSONNEL.
- NOTIFY OUTSIDE AGENCIES.
- REQUEST EXTERNAL ASSISTANCE.
- DECIDE ON EMERGENCY MEASURES.

MEDICAL

- GIVE PROMPT AID TO INJURED PERSONNEL.
- ESTIMATE SCOPE OF POTENTIAL MEDICAL PROBLEMS.
- DETERMINE NEEDS FOR ADDITIONAL MEDICAL ASSISTANCE.

HEALTH PHSICS

- DETERMINE EXISTING AND POTENTIAL CONTAMINATION PROBLEMS.
- EVALUATE AND LIMIT EXPOSURES TO PERSONNEL.
- ESTIMATE EXISTING AND POTENTIAL ENVIRONMENTAL PROBLEMS.

Figure 18-6-1. The responsibilities of emergency groups.

EMERGENCY ORGANIZATIONS

An emergency organization is built within the framework of the existing facility staff. For the best efficiency, an individual's responsibility during an emergency should be a natural extension of his or her usual job. Some persons also may be given a backup assignment to assist others when their primary duties have been discharged. For example, after a nuclear reactor operator accomplishes a safe plant shutdown, he may be free to aid in health physics or firefighting activities.

An Emergency Director must be named. This person is someone who normally serves in a supervisory capacity of a technical nature. A specific job title usually is designated for this person to ensure continuity in case of changes in personnel or multiple shift operation. The Emergency Director will supervise all activities from discovery of the accident until formally relieved by higher management. In smaller facilities, the Emergency Director also may be the highest manager.

This position cannot be taken as merely ceremonial. The Emergency Director must have a detailed working knowledge of the overall facility and must be free to supervise activities, with no other primary duties. The competence of the Director may spell the difference between a small incident and a major event. Duties of the Emergency Director are those presented in Figure 18-6-1 for management.

A clear line of succession is necessary in the event of injury or absence of the Director. Exactly how much authority and responsibility the Emergency Director has been given by the organization must be well established.

Emergency assignments of the facility staff are specified by organizational groups and/or title. The essential areas that must be included are as follows:

- Facility system control.
- Radiological support.
- Rescue and re-entry.
- Firefighting.
- In-house handling of injured personnel.
- Contamination control.
- Security and facility access control.
- Repair and damage control.
- Personnel accountability.
- Record keeping.
- Communications and logistics.
- Public relations.

Rather than to itemize persons involved with each of the above areas, it is more efficient to list in the plan the groups or titles and their specific, primary, and backup activities. One very important person is an emergency is the one who discovers it. Everyone in the facility must be familiar with the responses required should they come upon a situation that they believe calls for emergency action.

For a facility to maintain enough personnel and equipment for every contingency is impossible. Certain types of services are best provided by specialized outside groups. Off-site emergency support is from three sources: (1) Headquarters or other company facilities; (2) private organizations; and (3) public agencies. Examples of support functionas provided by external groups are listed in Table 18-6-2.

TABLE 18-6-2. OFF-SITE EMERGENCY SUPPORT.

Organizations	Type of Support – Function[1]
Headquarters Similar Facilities Consultants	Management – PR, GR, EP Administrative – CL, RK Technical – SC, R Health Physics – RS, CC
Nuclear Regulatory Commission Department of Energy Environmental Protection Agency State Health Department	Administrative – RK Management – PR, GR, EP Technical – SC Monitoring – RS
State Patrol Local Law Enforcement Emergency Departments Hospitals	Security – AC, EP Medical – AI Emergency Measures– RR, EP, F, CL Administrative – PA
Military Branches Civil Defense Authorities	Emergency Measures – EP, CL Security – AC, PR, RK

[1] Legend:
- System Control (SC)
- Radiological Support (RS)
- Rescue and Re-entry (RR)
- Firefighting (F)
- Aid to Injured (AI)
- Contamination Control (CC)
- Access Control (AC)
- Repair (R)
- Personnel Accountability (PA)
- Record Keeping (RK)
- Public Relations (PR)
- Government Relations (GR)
- Communications and Logistics (CL)
- Evacuation Procedures (EP)

Once the necessary support groups have been identified and letters of agreement obtained, a general notification scheme must be established. A chart is drawn to describe the chain of responsibility for notification of organization members in the event of an emergency. The chart ensures that support personnel are promptly made aware of the situation. Figure 18-6-2 is a sample notification chart for a nuclear power plant.

The relationship of the facility radiological emergency plan to other emergency procedures, both within and external to the site organization, is important and must be understood. Conflict of various plans can be a very serious problem, especially if actions called for in one plan are specifically prohibited by another. Situations may escalate dangerously while such discrepancies are being resolved.

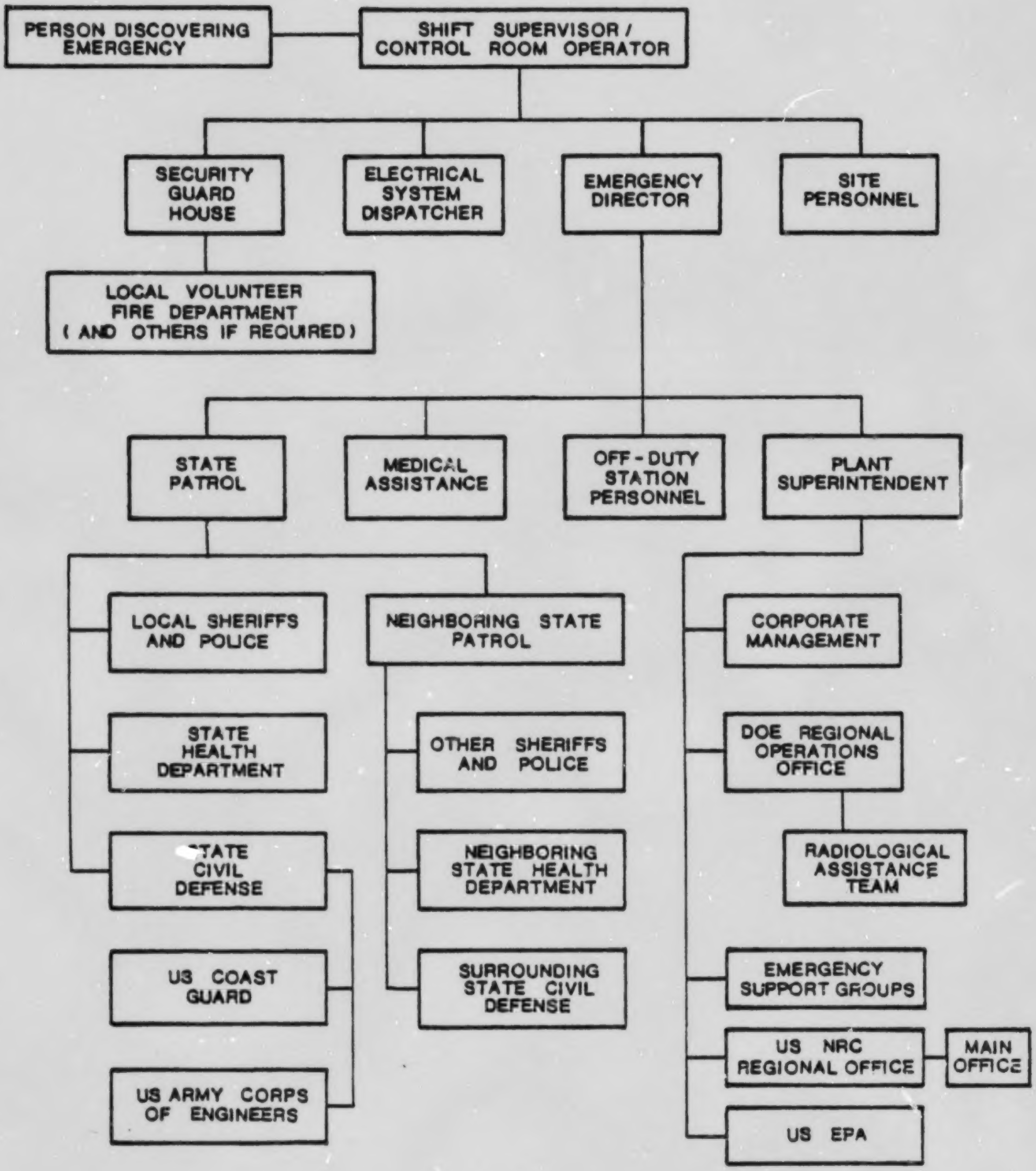

PERSON DISCOVERING EMERGENCY
SHIFT SUPERVISOR / CONTROL ROOM OPERATOR
SECURITY GUARD HOUSE
ELECTRICAL SYSTEM DISPATCHER
EMERGENCY DIRECTOR
SITE PERSONNEL
LOCAL VOLUNTEER FIRE DEPARTMENT (AND OTHERS IF REQUIRED)
STATE PATROL
MEDICAL ASSISTANCE
OFF - DUTY STATION PERSONNEL
PLANT SUPERINTENDENT
LOCAL SHERIFFS AND POLICE
NEIGHBORING STATE PATROL
CORPORATE MANAGEMENT
STATE HEALTH DEPARTMENT
OTHER SHERIFFS AND POLICE
DOE REGIONAL OPERATIONS OFFICE
STATE CIVIL DEFENSE
NEIGHBORING STATE HEALTH DEPARTMENT
RADIOLOGICAL ASSISTANCE TEAM
US COAST GUARD
SURROUNDING STATE CIVIL DEFENSE
EMERGENCY SUPPORT GROUPS
US NRC REGIONAL OFFICE
MAIN OFFICE
US ARMY CORPS OF ENGINEERS
US EPA

Figure 18-6-2. Sample Emergency Notification Chart for a nuclear power plant.

LEVELS OF AN EMERGENCY

There are several classes of emergencies with increasing degress of severity, each requiring certain types of action. Emergency action levels are utilized to describe classes of emergencies based upon their magnitude and the necessary response. These are specific dose rates, contamination levels, instrument readings, etc., used as thresholds for initiating a given emergency measure. The four degrees of emergencies are –

- Notification of Unusual Event.
- Alert.
- Site Emergency.
- General Emergency.

The first two classes provide early notification of minor events which could lead to more serious consequences or might be due to a serious condition not yet understood. A site emergency reflects the chance for significant radioactive releases: This class calls for full mobilization of emergency teams. The general emergency involves imminent chances of a severe breach in barriers against large quantities of radioactivity, such as a core melt in a power reactor. Evacuation may be required in this event. Table 18-6-3 describes the characteristics of each class.

The titles of these levels are not as important as their purpose, which is to trigger specific procedures at pre-established signals. The four classes above are for nuclear power plants; however, modification of scope or a reduction in the number of classes may be appropriate for other operations.

TABLE 18-5-3. CHARACTERISTICS OF EMERGENCY ACTION LEVELS.

Class	Description	Site Actions	Actions of Off-site Authorities
Notification of Unusual Event	Potential decrease in safety.	• Assess and respond. • Inform off-site groups. • Obtain staff augmentation. • Notify NRC if applicable.	Provide fire security or medical assistance if needed.
Alert	Actual or potential decrease in safety of substantial nature.	Those above plus: • Activate emergency centers. • Dispatch monitoring teams. • Update authorities with dose estimates and release data.	Those above plus: • Alert key personnel to standby status. • Monitor radiation levels.
Site Emergency	Actual or likely major failures in functions needed for public protection.	Those above plus: • Establish full consultations with NRC and State. • Provide a dedicated individual for release and dose estimated.	Those above plus: • Consult with site. • Provide periodic updates to public. • Place milk animals within two miles on stored feed. • Notify evacuation teams to stand by.
General Emergency	Actual or imminent loss of facility integrity and hazardous radiological release.	Same as above.	Those above plus: • Recommend shelter for two-mile radius and five miles downwind. • Evacuate as needed. • Relocate emergency center if needed.

EMERGENCY MEASURES

The traditional approach to preparation for accidents has been to establish a design basis accident (DBA) and to attempt to build an emergency organization to cope with this event. The DBA is a postulated, but almost incredible, sequence of malfunctions that automatic systems are designed to control. However, such an approach is no longer believed valid. It is generally recognized that a series of fairly small events could lead to a spectrum of possible accidents, some of which may be more severe than the DBA. The new approach is to develop a plan that covers any type of accident.

Once the plan has been initiated by the Emergency Director, the emergency actions taken in an individual case must be based upon the actual conditions that exist and that are projected at the time of the accident. A number of actions are possible in an emergency situation:

- Assessment Actions are taken during or after an accident to obtain and process information necessary to make decisions concerning specific emergency measures.
- Corrective Actions are measures taken to terminate an emergency. Such actions include shutting down of equipment, firefighting, and containing of materials.
- Protective Actions are emergency measures taken after an uncontrolled release of radioactive material has occurred to minimize or prevent radiological exposures to site personnel and members of the public. Protective Actions include warning, evacuations, and access control.

- Recovery Actions (cleanup and repair) are taken after an emergency to restore the facility, as nearly as possible, to its pre-emergency conditions.

For each type of action, detailed procedures must be available. Assessment actions should follow specific methods that will provide reasonable assurance that the magnitudes of releases, levels of contamination, and exposure rates can be determined in a timely manner. To ensure the proper response at every emergency action level, all material needed for assessment actions must be immediately available in an emergency-action system (EAS) kit. The kit contains preliminary information forms, guidelines for estimation of hazards, area and site maps, meteorological data, etc. Tables 18-6-4 through 18-6-6 are examples of some of these forms.

On-site measures are implemented first. The EAS kit should contain a map of the facility, such as that illustrated in Fiugre 18-6-3. The map can be utilized to identify or relocate pre-established evacuation routes, assembly areas, or emergency operations centers (EOCs). The latter are areas away from imminent danger and from which activities are directed. (The kit also should contain an Emergency Planning Zone Map, an example of which is provided later in this module as Figure 18-6-5.) There must be a means of warning visitors, contractors, and employees not having emergency assignments. Such individuals should assemble in a central location for a missing-persons check and radiological monitoring. Upon entering a facility, each visitor should be given an emergency instruction card such as that depicted in Figure 18-6-4.

TABLE 18-6-4. PRELIMINARY INFORMATION FORM IN EAS KIT.

EMERGENCY INFORMATION

A. Person Discovering the Emergency.

Name ______________________________

Time of Incident ______________ Date of Incident ______________

1. Where were you at time of incident? ______________________________

2. How did you know of emergency? ______________________________

3. How soon did you leave your location? ______________________________

B. Emergency Data and Notification Information.

1. Date and time of emergency. ______________________________

2. Type of emergency (describe briefly). ______________________________

3. Will the general public be affected? If so, describe conditions and levels of exposure and/or concentrations or radiological concerns. (If emergency involves gaseous release, include wind velocity and direction, whole-body and thyroid exposure rates at downwind boundary, and estimate of exposure time.) ______________________________

4. Plant status at present time. ______________________________

5. Agencies notified. ______________________________

6. Steps that have been taken and are planned to return to normal condition. ______________________________

7. What, if any, assistance will be needed? ______________________________

NOTE: If the emergency involves a gaseous release, the values in Table 18-6-3 may be used as emergency action levels.

TABLE 18-6-5. EMERGENCY ACTION LEVELS FOR GASEOUS RELEASE.

PROJECTED DOSE (Rem) TO THE GENERAL PUBLIC FROM PLUME	RECOMMENDED ACTION
Whole body < 1 Thyroid < 5	Alert
Whole body 1 to < 5 Thyroid 5 to < 25	Site Emergency
Whole body 5 and above Thyroid 25 and above	General Emergency

TABLE 18-6-6. SPECIAL ASSISTANCE INFORMATION FORM IN EAS KIT.

SPECIAL INFORMATION DATA

Available hospitals:
- South
  - Name ______ ______ ______
  - Tel. No. ______ ______ ______
  - Capacity ______ ______ ______
- North
  - Name ______ ______ ______
  - Tel. No. ______ ______ ______
  - Capacity ______ ______ ______
- East
  - Name ______ ______ ______
  - Tel. No. ______ ______ ______
  - Capacity ______ ______ ______
- West
  - Name ______ ______ ______
  - Tel. No. ______ ______ ______
  - Capacity ______ ______ ______

Areas of evacuation:
- South ______ ______ ______
- North ______ ______ ______
- East ______ ______ ______
- West ______ ______ ______

Available hotels, motels:
- South ______ ______ ______
- North ______ ______ ______
- East ______ ______ ______
- West ______ ______ ______

Available halls, resort areas:
- South ______ ______ ______
- North ______ ______ ______
- East ______ ______ ______
- West ______ ______ ______

Aerial-survey service:
- Name ______ ______ ______
- Tel. No. ______ ______ ______

List of key personnel:
- Name ______ ______ ______
- Position ______ ______ ______
- Tel. No. ______ ______ ______

List of state and federal agencies:
- Name ______ ______ ______
- Tel. No. ______ ______ ______

List of emergency reporting requirements:
- Management ______ ______ ______
- Medical ______ ______ ______
- Health Physics ______ ______ ______

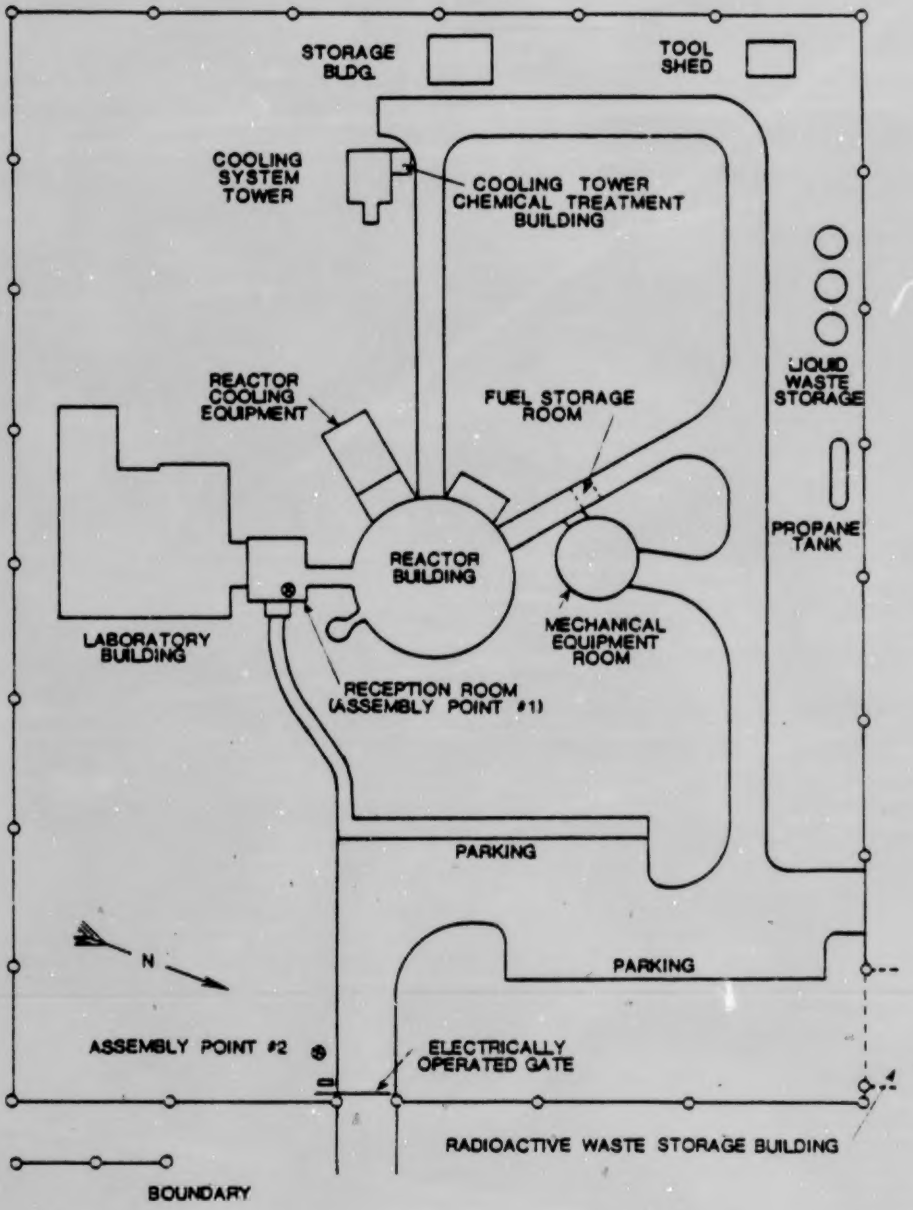

STORAGE BLDG.
TOOL SHED
COOLING SYSTEM TOWER
COOLING TOWER CHEMICAL TREATMENT BUILDING
LIQUID WASTE STORAGE
REACTOR COOLING EQUIPMENT
FUEL STORAGE ROOM
PROPANE TANK
REACTOR BUILDING
MECHANICAL EQUIPMENT ROOM
LABORATORY BUILDING
RECEPTION ROOM (ASSEMBLY POINT #1)
PARKING
N
PARKING
ASSEMBLY POINT #2
ELECTRICALLY OPERATED GATE
RADIOACTIVE WASTE STORAGE BUILDING
BOUNDARY

Figure 18-6-3. Site map for research reactor facility.

VISITOR

Actions in the Event of an Emergency

1. If the evacuation alarm sounds, pay specific attention to any announcement made over the plant paging systems and comply with those instructions.
2. If evacuation is necessary, proceed immediately to the primary evacuation assembly point (Auditorium) and follow the instructions of the Emergency Director.
3. If you happen to be in an area where you do not have an escort immediately available and are not familiar with the direction to the assembly point, request assistance from any other individual in the immediate area.

EMERGENCY SIGNALS

1. Distinct Pulse Tone ∿∿∿∿∿∿∿∿ (Alert)

   Sounded through the plant intercom system for 10 seconds followed by an announcement of the emergency condition and the area affected. This will be performed twice.

2. Distinct Steady Tone ________ (Site Emergency)

   Sounded through the plant intercom system. The alarm shall be sounded for 10 seconds followed by the announcement and directions for evacuation, and will then be reactivated for an additional 5 minutes.

3. All clear — A distinct siren tone ∩ sounded for 10 seconds followed by the announcement "All Clear."

Figure 18-6-4. Sample visitors emergency instruction card.

Emergency equipment may be needed. Respiratory equipment, protective clothing, or radioprotective drugs, such as potassium iodide, are examples. The location and means of distribution of such materials is a part of the emergency plan. Table 18-6-7 is a typical list of emergency equipment.

TABLE 18-6-7. RADIOLOGICAL EMERGENCY EQUIPMENT FOR NUCLEAR FACILITIES.

Quantity	Item
	Anit-Contamination Clothing (per team member).
1 pair	Coverall (anti-contamination)
4 pairs	Gloves (rubberized)
2 pairs	Shoe covers (rubber)
2	Head covers (hoods)
1	Full face mask with cartridge
1 roll	2-inch masking tape
(Additional quantities of anti-contamination clothing in central location.)	
	Radiation Detection Instruments and Accessories (per four-man team).
4	Alpha detection instruments
1	Neutron-proton recoil shield
1	Low energy gamma detector
4	Low level beta-gamma detectors
4 sets	Head phones
4	High-level beta-gamma detectors, Rodector (10,000 R/hr full scale)
2	Air samplers (battery operated)

1 box	Filter paper
1	Dosimeter charger
12	Dosimeters
6	Neutron activation detectors, (Indium Foils)
6	Flashlights with batteries
12	Spare flashlight batteries
4	Complete self-contained breathing apparatus with one extra bottle each

Area and Personnel Control Equipment

1	Health Physics Handbook (with reference tables)
1	Notebook
2	Retractable pens
4	Grease pencils
1	Area access log
1	Survey log
1	Survey grid map
80	Nasal swabs
40	Swab containers
100	Smear papers
100	Glassine envelopes
1	Reel of barricade ribbon (bright color, 5000 feet)
100	Contaminated material stickers
5	Radiation area signs
25	Large plastic bags
1	First aid kit
1 pt.	Anti-fog solution

CONTAMINATION AND EXPOSURE CONTROL

Contamination control measures for the immediate site should be detailed in the plan. Larger facilities may also establish an exclusion area which is a zero-population zone 0.2-1 mile in diameter around the fenced boundary. The plan describes measures for restricting access, agricultural product quarantine, analysis of water supplies, control of effluents, and decontamination of personnel and property.

Decontamination may be defined as the removal, fixing, or decay of unwanted radioactive substances in order to reduce a health hazard or to permit the reuse of equipment, buildings, or terrain. It is a complex problem that requires much custom tailoring of individual needs. Any complete emergency plan provides instructions for gathering of information on the types and amounts of contamination involved. The locations of decontamination equipment and supplies must be clearly identified in the plan. Such materials should be strategically positioned near, but not too near, areas that could become contaminated.

The organization responsible for decontamination will receive information directly from radiological monitoring teams. In order to prevent the spread of contamination, all personnel and equipment are monitored before they leave affected areas. Contaminated individuals must proceed immediately through decontamination procedures specified in the plan. Equipment also may be cleaned as necessary or time permits. Table 18-6-8 summarizes some general techniques for decontamination.

TABLE 18-6-8. DECONTAMINATION METHODS.

Type	Technique	Comments
Terrain	Fixing contamination	Spraying, oiling, plowing, flooding, paving
	Translocation of soil	Fix contamination; remove and bury soil
Equipment or Surfaces	Disposal	Often the cheapest method
	Ultra-sonic vibrations	Excellent for small, solid objects
	Scrubbing or scouring	Water and detergent, high-pressure spray, steam-cleaning, sand-blasting or other abrasives
	Vacuuming	Loose contaminant
	Special agents	Acid mixtures — nonporous or reactive surfaces (tools, concrete) Caustic mixtures — painted surfaces (not generally recommended) Solvents — nonporous surfaces (greasy or waxed) Complexing agents — nonporous surfaces (unweathered)
Personnel	Washing	Soap and water (water only for wounds)
	Mild abrasive	Lava with scrub brush
	Chemical solutions	Carbose, potassium permanganate, citric acid

Another extremely complicated problem, which occurs primarily during rescue and recovery operations, is the control of personnel exposure. Control requires perhaps the most judgment of all other factors during a radiological emergency. The official in charge must carefully examine any proposed measure that involves radiation exposure by weighing the risks against the benefit to be gained. Situations that call for exposures sufficient to pose an opportunity for injury may be those directed toward saving a human life, recovering a deceased victim, or protecting health and property. Rigid upper limits should not be established, especially in the case of saving lives. Table 18-6-9 explains some guidelines that may be included in the emergency plan.

TABLE 18-6-9. GUIDELINES FOR EXPOSURES IN RESCUE AND PROTECTION.

SAVING A HUMAN LIFE

1. Attempts to rescue victims in a nuclear accident should be regarded in the same way as any other emergency action involving rescue of victims.
2. Use any protective equipment available within the time frame of the situation, especially for airborne hazards.
3. Rescue activities that involve substantial personal risk should be performed by volunteers, preferably by those who do not intend to have children.
4. The probability of success must be considered before a decision is made to take any action.
5. In establishing an exposure limit guide –
    a. Do not hesitate to take 25 Rem/single exposure or 100 Rem/day. Higher exposures require indiividual consideration.

b. If the expected exposure based on a physical estimate will exceed 100 Rem, possible errors of ±25% for personnel dosimeter measurements and ±35% for survey meters must be considered. The type of measuring devices available should be detailed in the plan.

ACTIONS TO RECOVER DECEASED VICTIMS

1. The actions should be well planned, and exposures should remain within occupational guides.
2. Remote-recovery devices should be used where possible.
3. The planned exposure of an individual in the recovery should not result in a total of more than 3 Rem for the quarter, 5 Rem for the past year, or 5(N-18) Rem for the person's lifetime, whichever is limiting. (N - age of individual.)

ACTIONS TO PROTECT HEALTH AND PROPERTY

1. Where a hazard following a nuclear incident is such that life would be endangered or that health and property would be jeopardized to the extent of threatening public safety, the criteria for saving a life above would apply.
2. Otherwise, occupational exposures should not be exceeded unless the reduction of a potential hazard can be accomplished. In this case, no emergency worker should receive more than 25 Rem.

RELEASES TO THE ENVIRONMENT

Emergency preparedness is related to two predominant exposure pathways from a radiological release to the environment:

- Plume Exposure Pathway: (1) Whole-body exposure to gamma radiation from the radioactive cloud (or plume) and deposited material; or (2) inhalation exposure from the passing radioactive plume. The time could range from hours to days for plume exposure.

- Ingestion Exposure Pathway: The principal exposure is from ingestion of contaminated water or foods such as milk or fresh vegetables. Ingestion occurs over a period that varies from hours to months.

In order to deal with these two pathways, Emergency Planning Zones (EPZs) are defined. EPZs are areas for which planning is recommended to ensure prompt and effective actions for public protection. The size of the zone is governed by the spectrum of accidents postulated for the facility. The EPZ implies a circular area, but its actual shape depends upon the characteristics of the site. Table 18-6-10 lists some guidelines for zone sizes for a large nuclear facility. Figure 18-6-5 is an example of an EPZ map, a copy of which is placed in the EAS kit. The appropriate local authorities within the zone are integrated into the overall plan.

TABLE 18-6-10. GUIDANCE ON SIZE OF THE EMERGENCY PLANNING ZONE.

Exposure Source	Critical Organ and Exposure Pathway	EPZ Radius (Nuclear Power Plant)
Plume Exposure Pathway	Whole Body (external) Thyroid (iodine release) Other organs (inhalation)	About 10 mile radius*
Ingestion Pathway**	Thyroid, whole body, bone marrow (ingestion)	About 50 mile radius

*Judgment should be used in adopting this distance based upon considerations of local conditions such as demography, topography, land characteristics, access routes, and local jurisdictional boundaries.

**Processing plants for milk produced within the EPZ should be included in the emergency response plans regardless of their location.

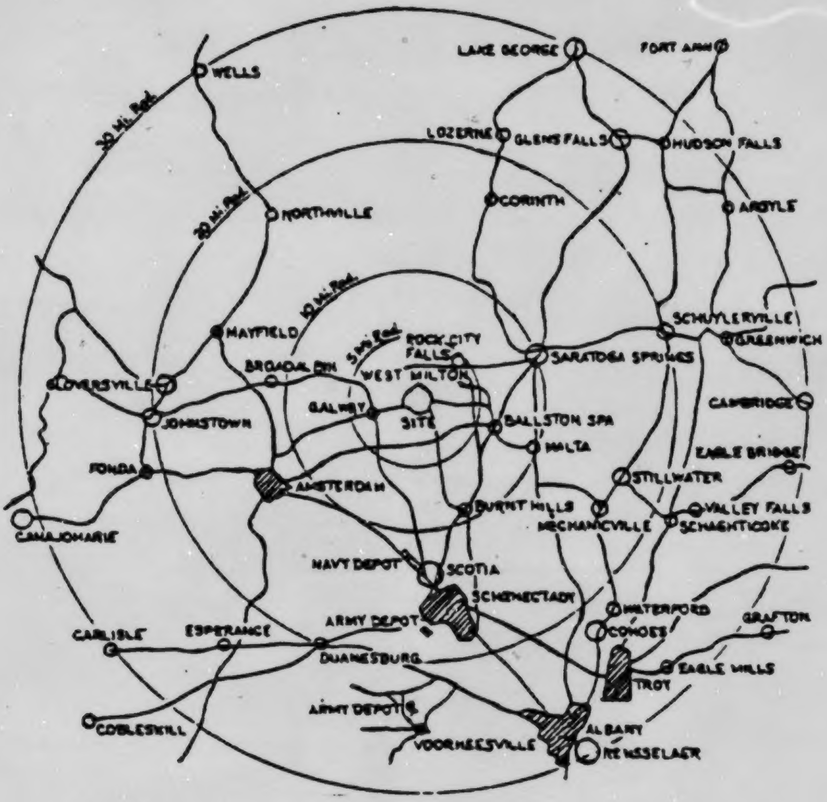

30 Mi. Rad.
20 Mi. Rad.
10 Mi. Rad.
5 Mi. Rad.
WELLS
LAKE GEORGE
FORT ANN
LOZERNE
GLENS FALLS
HUDSON FALLS
CORINTH
ARGYLE
NORTHVILLE
MAYFIELD
SCHUYLERVILLE
GREENWICH
ROCK CITY FALLS
SARATOGA SPRINGS
BROADALBIN
WEST MILTON
GLOVERSVILLE
GALWAY
SITE
BALLSTON SPA
CAMBRIDGE
JOHNSTOWN
MALTA
EAGLE BRIDGE
FONDA
AMSTERDAM
STILLWATER
BURNT HILLS
MECHANICVILLE
VALLEY FALLS
SCHAGHTICOKE
CANAJOHARIE
NAVY DEPOT
SCOTIA
SCHENECTADY
WATERFORD
ARMY DEPOT
COHOES
GRAFTON
CARLISLE
ESPERANCE
DUANESBURG
EAGLE MILLS
TROY
ARMY DEPOT
COBLESKILL
ALBANY
VOORHEESVILLE
RENSSELAER

Figure 18-6-5. Emergency planning zone map
(from Fitzgerald).

A release to the environment may originate from a breach in the facility containment or from planned or unplanned releases through the normal ventilation system. In any event, guidelines for the emergency director should be immediately available in the emergency kit. Guidelines may include whole-body dose rate curves (Figure 18-6-6) and maximum permissible level (MPL) guidelines (Table 18-6-11). Such values are used only as guidelines and must be heavily augmented by measured data.

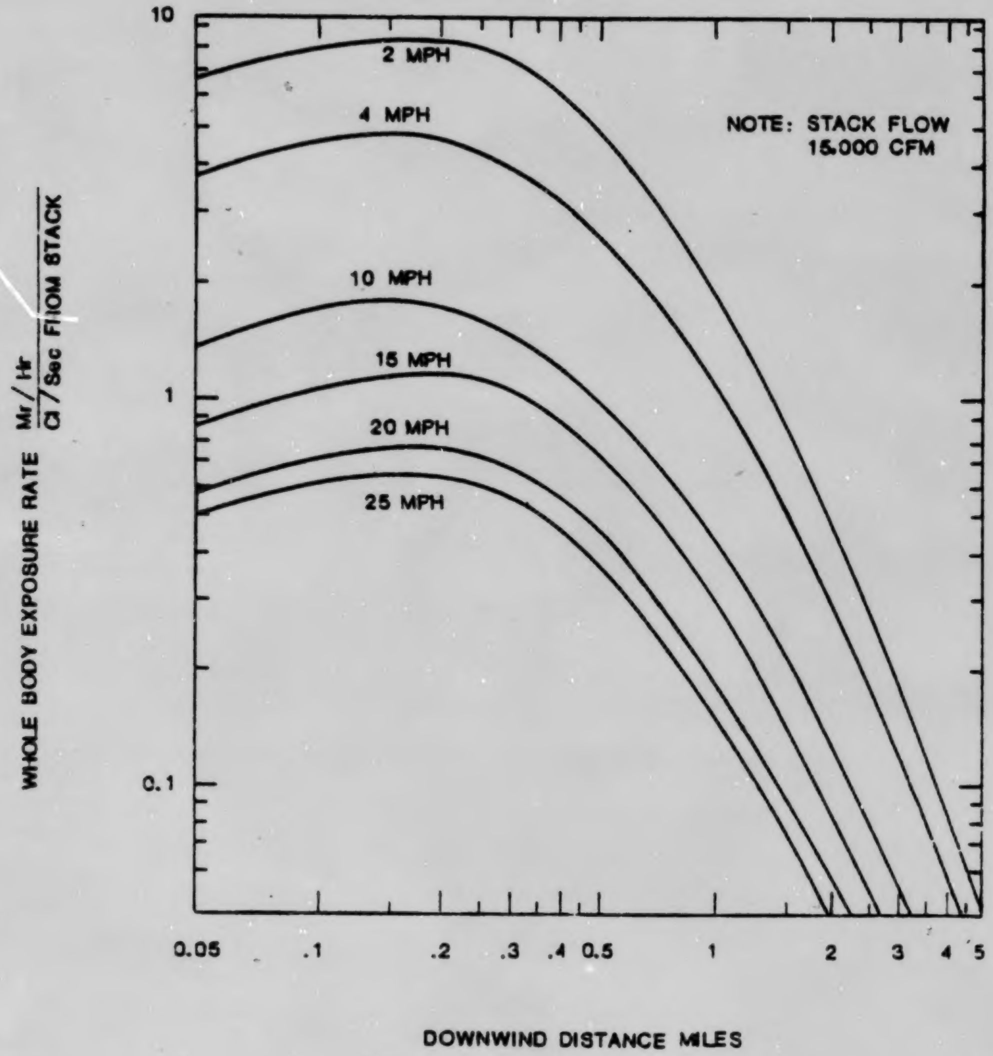


Figure 18-6-6. Example dose guideline curves for EAS kit.

TABLE 18-6-11. MAXIMUM PERMISSIBLE CONCENTRATIONS OF RADIOACTIVITY IN FOOD, AIR, AND BODY.

MPC IN FOOD

Radionuclide	MPC (water), pc cm^1	MPL (milk), pc cm^1	MPL (food), pc day
Mixed F.P.	10^{-7}	10^{-7}	
^{90}Sr	10^{-6}	10^{-6}	2.5×10^{-3}
^{89}Sr	10^{-4}	10^{-4}	2.5×10^{-1}
^{131}I	2×10^{-5}	2×10^{-5}	5×10^{-2}

MPC IN AIR

Radionuclide	MPL (air), pc cm^3
Mixed F.P.	10^{-9}
^{90}Sr	10^{-10}
^{89}Sr	10^{-8}
^{131}I	3×10^{-9}

MPC IN BODY

Radionuclide	MPC (urine), dis min, 1500 cm^1	MPL (feces), dis min, 1500 cm^1	MPL (whole body) pc
Mixed F.P.			
^{90}Sr	2×10^3	4×10^3	2
^{89}Sr	4×10^3	8×10^3	4
^{131}I			0.7

TRAINING AND EXERCISES

Emergency organizations are only as efficient as they are well trained. If personnel have to stop and think about an action which should be second nature, valuable time will be lost. The emergency plan should contain a complete description of the frequency and types of training to be given to emergency personnel. Everyone in the organization described earlier must have some type of classroom training, which usually involves his or her primary emergency duty plus some associated area. For example, a firefighter also will receive health physics training. Those who deal directly with system control will have highly specialized training. Nuclear power reactor operators now are required to train for emergencies on computerized reactor simulators that recreate abnormal situations for instructional purposes. Trainers should be qualified specialists. Some off-site training will be required; however, organization members should train each other whenever possible to promote teamwork.

An important extension of classroom training is the conduct of periodic drills and exercises. Drills can be thought of as surprise emergency alerts of a general type, in which facility personnel carry out their initial assignments as they would be expected to do under real circumstances. This might include assembling at a given location, distributing emergency equipment, or setting up a control point. Emergency exercises, on the other hand, are full-scale simulations that pose realistic scenarios that require all of the elements of the emergency plan, including judgment. They are held in order to test the readiness of both personnel and equipment. At a minimum, each exercise should test internal communication links and off-site notification procedures.

Psychological studies indicate that the poeple who perform best in emergencies are those who have experienced them before. Exercises, if properly conducted, will condition the participants to the point that when they are faced with the real thing, they will react appropriately. They also give emergency organization members the opportunity to practice what they have learned in the classroom.

Basic types of exercises are –

- Instruction exercise. This exercise is conducted solely for training with a demonstration-performance approach.
- "Walk-through" exercise. Participants perform emergency operations step-by-step in rather slow motion, and mistakes are corrected as they occur.
- Communications exercise. This exercise involves only the communications system.
- Simulation exercise. A complete incident is staged, with all organizations responding.

An emergency exercise can be either announced or unannounced. There are advantages and disadvantages to each. One effective approach is to announce that an exercise is imminent, without giving specific details about the type or date.

In planning a drill or exercise, one key point is the limiting of scope. Some ogranizations actually will respond; others will be notified with no response required. Also, extra incidents may be interjected by an exercise director and umpires to prevent activities from lagging. A complete script is essential, and a safety plan also should be written. The latter requires a safety officer who has the authority to call off an exercise when the participants' safety is in jeopardy. Finally, a critique and recommended followup action are produced. The critique and followup can be sensitive processes, as it is understandably difficult for participants to be objective about their own performance. Table 18-6-12 lists some training and exercises needed for emergency personnel at nuclear facilities.

TABLE 18-6-12. TRAINING AND EXERCISES FOR EMERGENCY PERSONNEL AT NUCLEAR FACILITIES.

Group	Training	Frequency	Possible Exercises or Drills	Frequency
Directors and System Officers	Notification procedures Assessment actions System control	A A SA	Implementation drill Simulation exercises Simulation exercises	SA A SA
Medical Teams	First aid Health physics	SA A	Simulation exercises Walk-through exercises	A A
Radiological Teams	Radiation monitoring First aid	SA A	Simulation exercises Instructional exercises	A A
Fire Brigades	Fire suppression Health physics	SA A	Imp. drill and exercises Instructional exercises	Q and A A
Rescue and Re-entry	Rescue equipment Radiological protection	SA A	Walk-through exercises On-site drill	Q Q
Local Services	Notification procedures Access control Evaluation procedures	A A A	Implementation drill Simulation exercises Communications exercise	SA A A
Headquarters Personnel	Notification procedures Government relations Evacuation procedures	A A A	Implementation drill Communications exercise Communications exercise	SA A A

A: Annually SA: Semi-annually Q: Quarterly

POST-ACCIDENT ACTIVITIES

After an accident has been either terminated or sufficiently controlled, activities can proceed in an orderly manner toward restoring the facility as nearly as possible to pre-emergency conditions. Some or all of the following activities will be necessary:

- Finish decontamination activities.
- Followup personnel exposures.
- Establish criteria for replacing equipment.
- Repair or replace damaged equipment.
- Replenish and test supplies and emergency equipment.
- Conduct meetings with participating groups, discussing what happened and the actions of each group.
- Review the cause of the emergency, and institute measures to prevent it reoccurrence.
- Review and modify the emergency plan itself, if necessary. (This should be done periodically even if the plan has not been used.)
- Complete required reports to local, state, and federal agencies. Such groups may have the authority to require various changes in operating or emergency procedures.

The emergency plan should identify details for accomplishing each of these tasks.

Planning for radiological emergencies is a complex undertaking that requires input from a variety of groups having widely differing viewpoints. If there are any general rules to follow they are:

- Decide upon the amounts of equipment and personnel needed, and add a little more.
- Ensure that everyone is intimately familiar with his or her assignment.
- Evaluate, train, and test: Don't become complacent!

EXERCISES

1. Compare and contrast the needs for emergency planning –
    a. A university nuclear laboratory housing a 1-watt training reactor and several low-level (a few μCi each) beta-gamma sources for counting experiments.
    b. A large medical center in an urban area handling considerable amounts of low-energy sources such as tritium and carbon-14.
    c. A nuclear power plant site.
2. Briefly describe a training exercise or drill for –
    a. Handling contaminated and injured personnel.
    b. Rescuing an unconscious victim in a high radiation field.
    c. Notification of off-site agencies.

MATERIALS

Access to any nuclear facility and its existing emergency plan.

PROCEDURES

The purpose of this procedure is to allow the student to apply the principles presented in this module. In doing so, knowledge obtained from previous module in this course will be required.

Tour any existing nuclear facility with someone who is knowledgeable about its layout and design features. (If this is not possible, try to obtain a safety analysis report or other detailed description of such a facility.) Outline an emergency plan for the particular operation involved. Using the existing emergency plan, compare it to yours. Discuss reasons for the differences and suggestions for improvement of the current plan.

DATA TABLE

None.

REFERENCE MATERIALS

Fitzgerald, J.J. Applied Radiation Protection and Control. New York: Gordon and Breach, 1970.

Purrington, R.G. and Patterson, Wade. Handling Radiation Emergencies. Boston: National Fire Protection Association, 1977.

U.S. Nuclear Regulatory Commission. Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants, NUREG-0396, 1978, and Emergency Planning for Nuclear Power Plants, Reg. Guide 1.101, 1977. (Also see Reg. Guides 3.42 and 2.6.) Springfield, VA: National Technical Information Service.

________. Code of Federal Regulations, Appendix E, "Emergency Planning and Preparedness for Production and Utilization Facilities." Washington, DC: U.S. Government Printing Office, latest issue with latest Supplements.

TEST

1. What is the most frequent cause of accidents involving nuclear materials? How will emergency planning help minimize accident consequences?

2. State the main goal of an emergency plan and list three broad objectives that will assist in the accomplishment of the plan.

   Goal:

   Objectives:

3. Briefly describe the three main areas of responsibility in a nuclear emergency.

4. List five off-site agencies, and describe in one or two words a support function of each.

5. Sketch a primary notification chart for a large nuclear facility.

6. Describe the concept of emergency action levels.

7. Describe the four general types of actions that may be taken during an emergency.

8. List two types of decontamination techniques for equipment and surfaces.

9. What items should be in an Emergency Action System kit?

10. Briefly discuss the major considerations for a lifesaving effort in a high radiation field.

11. List the two primary pathways of exposure to man from a radiological release.

12. What types of training are required for –
Firefighters at nuclear facilities?

Rescue and re-entry teams at nuclear facilities?

13. List six pieces of emergency equipment that should be available at a nuclear facility.

14. Define the following terms:
    a. Emergency plan.

    b. Emergency director.

    c. Action levels.

    d. Site emergency.

    e. General emergency.

    f. Assessment actions.

    g. Protective actions.

    h. Emergency operations center.

    i. Emergency planning zone.

    j. Exclusion area.

k. Walk-through exercise.

15. Discuss activities conducted after a nuclear accident.

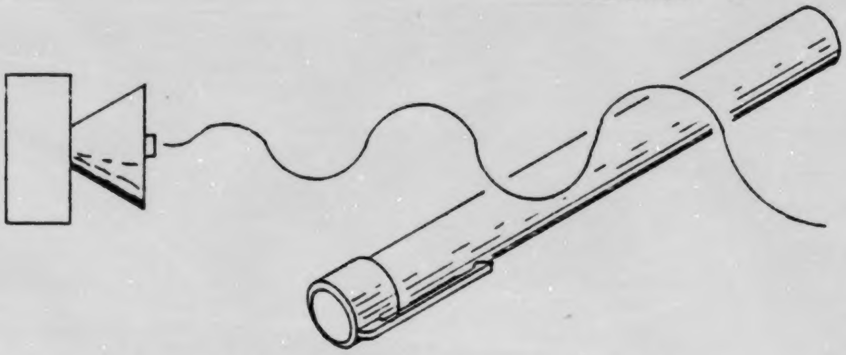
NUCLEAR TECHNOLOGY

MODULE 18 - 7

EMERGENCY DRILLS FOR NUCLEAR FACILITIES

RADIOLOGICAL
EMERGENCIES

COURSE 18



CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

COURSE 18 RADIOLOGICAL EMERGENCIES

Module 18-1	General Procedure for Radiological Emergencies
Module 18-2	Emergency Equipment for Nuclear Facilities
Module 18-3	Surface Contamination – Decontamination
Module 18-4	Criticality Control
Module 18-5	Control of Radiological Hazards
Module 18-6	Emergency Planning for Nuclear Facilities
Module 18-7	Emergency Drills for Nuclear Facilities

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INTRODUCTION

Emergency drills and exercises for radiological emergencies are time-consuming and experience expensive; therefore, why have them? They quickly are justified when one accepts the fact that there is no room for substitutes of qualified emergency-team personnel who are experienced in the health physics and the health and safety aspects of radiological emergencies. It is a known fact that people will perform much better during their response to a radiological emergency once they have experienced participation in an emergency situation. This phenomenon is the result of psychological conditioning and of the development of decision-making skills acquired from their participation in the first emergency. The more emergencies people are involved in, the better they perform, at least from the psychological-conditioning and the decision-making processes. The same can be said for training – the more training they receive, the better they respond; therefore, the end result of training and participation in drills and exercises is experience.

Fortunately, emergency-team personnel are presented few opportunities to combat radiological emergencies; consequently they lack the vital and all-important experience. As mentioned earlier, there is no substitute for experienced and qualified personnel trained in combating and taking control of radiological emergencies. Emergency-team personnel can obtain this necessary training and experience through participation in well-planned and realistic emergency drills and exercises. If properly planned and conducted, these drills and exercises will condition the participants to react appropriately when they are faced with a real emergency.

MODULE PREREQUISITES

The student should have completed Course 1, "Radiation Physics"; Course 2, "Radiation Protection I"; Course 11, "Radiation Detection and Measurement"; Course 17, "Radiation Protection II"; and all previous modules in Course 18.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Explain why emergency drills and exercises are necessary.
2. Discuss the advantages and disadvantages of conducting an unannounced exercise.
3. Describe the responsibilities of the public information officer.
4. List and explain the responsibilities of the exercise officer.
5. Design and plan a realistic radiological emergency drill and exercise.
6. Participate in a radiological emergency exercise, and demonstrate appropriate and correct responses to the following:

   Evaluation and assessment of the emergency situation and conditions.

   Evacuation of personnel and use of emergency equipment.

   Assessment of radioactive contamination.

   Recovery from the accident, including decontamination and facility re-entry.

TRAINING FOR RADIOLOGICAL EMERGENCIES

The purpose of training emergency team personnel is to develop knowledge and to provide them with experience in making appropriate decisions and correct responses to an emergency situation. Lack of knowledge and experience in combating and mitigating the consequences of a radiological incident can result in erroneous decisions and inappropriate actions that can escalate the incident to a more serious situation. In almost all emergencies that involve radioactive materials, emergency-team personnel will be the first on the scene. To be effective, these personnel must have the knowledge and training to protect themselves and other team members and to rescue injured personnel without escalating the incident to a more hazardous situation; for example, the spreading of radioactive contamination to other areas of the facility. Emergency-team personnel who lack knowledge in the basic principles of radiation protection will NOT be in a position to make valid and appropriate decisions that affect the emergency operations. The development of knowledge, skills, and experience through training will dispel fear of the unknown. The acceptance of scare information about radiation and radioactivity can be just as harmful to the technician as blundering into an emergency situation without regard for taking control of hazards that pose a threat to public health and safety because such acceptance can hinder the decision-making process and result in failure to act. One now can say that the keys to effective emergency operations are knowledge and skills. Although some of these knowledge and skills can be obtained from other disciplines, the majority of the required training must originate from classroom sessions and participation in drills and exercises for radiological emergencies.

Fortunately, radiological emergencies are infrequent, but when they do occur, emergency-team personnel must be prepared. Participation in an emergency operation in response to a real radiological emergency is not the time to conduct training. Training can be classified into two categories: (1) classroom work and (2) drills. One without the other is insufficient.

CLASSROOM SESSIONS

The time spent in classroom work on radiological emergencies can vary from a few hours of review to a detailed and comprehensive course of several weeks duration. The outline suggested in Table 18-7-1 covers the subjects that should be included in a comprehensive course of instruction. Segments from the total outline may be extracted and adapted for short review sessions and for the necessary retraining required to correct detected weakness or other deficiencies of the overall emergency plan.

TABLE 18-7-1.
TRAINING COURSE OUTLINE FOR RADIOLOGICAL EMERGENCIES

1. NUCLEAR PHYSICS
    - Radiation and radioactivity.
    - The structure of the atom.
    - Atomic mass units.
    - Atomic weight.
    - Radioactive decay.
    - Radioactive half-life.
2. DETECTION AND MEASUREMENT
    - Units of radioactivity.
    - Alpha detection instruments and monitoring techniques.
    - Beta-gamma detection instruments.
    - Dosimeters, including pocket ion-chambers, film badges, and TLD's.
    - Air samplers – sample collection and analysis.
    - Radioactive contamination – smear sample collection and analysis.
3. PRINCIPLES OF PROTECTION
    - Behavior of radiations.
    - Inverse square law.
    - Time.
    - Distance.
    - Shielding.
    - Contamination control and decontamination.
    - Use of protective clothing and equipment.
    - Radioactive materials transport packages and transportation regulations.
4. EMERGENCY OPERATIONS
    - Training and coordination of off-site support agencies.
    - Assignment of responsibilities to individual support agencies.
    - Emergency medical facilities and hospitals.
    - Public information.
    - Firefighting – prevention and protection.
    - Rescue of injured personnel.
    - Notifications and reports to applicable governmental agencies.
    - Evacuation and area control.

EMERGENCY DRILLS AND EXERCISES

Emergency drills and exercises provide a system, or method, by which participants can gain, in a relatively safe manner, experience in emergency operations. As an added benefit, exercises give the emergency-team personnel an opportunity to practice what has been learned in the classroom – to develop manipulative skills, assessment abilities, and corrective actions for mitigation of the consequences of the emergency. Particularly important for the personnel is the ability to function efficiently under simulated, but realistic emergency conditions and to operate the instruments and other equipment utilized in radiological emergencies. It is one thing to use a self-contained breathing apparatus in a classroom; it is quite another to use this equipment under the psychological stresses associated with realistic emergency conditions such as the rescue of an injured person in a smoke-filled, dark room.

Practice drills, if realistically staged with carefully-developed objectives, can identify deficiencies in the emergency plan and in the abilities and preparations of the participants for handling a radiation accident. Upon completion of the drill, a critique should be held. Experienced observers then can advise all participants of their mistakes, lack of judgment in decision-making, and weakness in manipulative skills. These observers quickly can identify discrepancies in the emergency plan. Revisions in the plans and retraining of the participants in the identified areas of weakness always should follow each exercise. This upgrading of the plans and skills will assist in the preparation for the real radiation accident if and when it occurs.

A final reason for practice exercises is to identify and to smooth out organizational jurisdictions. Emergencies that occur at nuclear facilities usually require assistance from off-site support agencies. These organizations include municipal fire and police departments, emergency medical assistance and ambulance services, hospitals, radiological assistance teams, and other related agencies. These organizations normally do not work together. An exercise that involves all of them provides the opportunity to ensure that their operations are not working at cross purposes.

EXERCISE PLANNING

Radiological emergency drills, either large or small, require a certain amount of detailed planning for the exercise to be effective. This initial planning is one of the more important aspects of an exercise. The initial planning of an exercise is the first phase in the design, the training exercise to be conducted. There are several items that must be considered in order that the exercise will be practical, effective, and beneficial to the participants and the facility or organization. This initial planning usually begins with a meeting of those personnel who will design and outline the exercise to be conducted. At this meeting, these personnel should complete the steps outlined and explained in Table 18-7-2.

TABLE 18-7-2

STEPS IN THE PLANNING OF AN EXERCISE

1. DETERMINE THE TYPE OF EXERCISE, AND DEFINE THE EXERCISE LIMITS.

2. DETERMINE WHO WILL PARTICIPATE IN THE EXERCISE – individuals, groups, or off-site support agencies. NOTE: If off-site support agencies are to be involved, representatives of the organizations must be present.

3. DETERMINE THE OBJECTIVES TO BE ACCOMPLISHED DURING THE EXERCISE. Put these objectives in writing in order that they can serve as a reference source during preparation of the final exercise. One important item to remember is that it is very difficult to design and conduct a practical exercise that will accomplish the requirements specified from a multitude of objectives. Therefore, keep the objectives as few as possible, and do not attempt to accomplish two phases of training with one exercise. In addition, the final accepted objectives for the exercise should be simple, specific, and straightforward. This is an important phase of exercise planning, and without appropriate defined objectives the exercise will have very little value. In simple terms – if you don't know where you are going, you will never know when you get there.

4. PREPARE AN OUTLINE OF THE EXERCISE, KEEPING IN MIND THE ESTABLISHED OBJECTIVES. The outline probably will be brief and consist of only major headings, but it will form the framework for writing the exercise to be conducted.

5. ESTABLISH A TENTATIVE DATE AT WHICH TO CONDUCT THE EXERCISE. This step is important because it will place the planners on a schedule for completing the exercise and will allow the involved groups and off-site support agencies to prepare their scheduled activities so they may participate in the exercise with a minimum of descriptions to their normal duties and responsibilities.

6. THE FINAL STEP OF THE INITIAL PLANNING IS THE OBTAINING OF PERMISSION TO CONDUCT THE EXERCISE. Most exercise planners do not have the authority to commit personnel and equipment for a training exercise. The authority to conduct the exercise usually rests with facility management and for large exercises involving off-site support agencies, this authority will include hospital administers, city managers, and the administers of other governmental agencies.

DESIGNING THE EXERCISE

When the permission to conduct the exercise has been obtained and the tentative date for the exercise has been approved, the preparation of the exercise is the next step to be accomplished. The first step in writing the exercise is to assign an exercise director, who will have the overall responsibility for ensuring that the exercise is planned and conducted in such a manner as to accomplish the objectives specified for the exercise. The director is responsible for the establishment of a working committee that will prepare the exercise and work out the details for logistical support of manpower and equipment required for the exercise. The members of this committee also may function as observers during the exercise. Finally, the director must coordinate the completion of the assigned task, conduct the critique of the exercise, and prepare a written summary of the results of the exercises. This summary will include deficiencies noted in the exercise plan and in individuals in order that the plan can be upgraded and in order that personnel weakness can be corrected through additional training.

Since there are several types of exercises, the particular type of exercise to be conducted must be established. Table 18-7-3 consists of an outline of suggested types of exercises and is presented for use in designing the exercise to be conducted.

Determine whether the exercise is going to be announced or unannounced. There are advantages and disadvantages in both cases. An unannounced exercise places the participants under the same (perhaps ever more) stress than they would be under in a real incident. This, however, is not without some

TABLE 18-7-3

OUTLINE OF EXERCISE TYPES

1. TRAINING EXERCISE. This is an exercise conducted solely for training. It gives the participants the practice in the skills they have learned in the classroom.

   An exercise of this type may consist of studying the behaviors of radiation and radiation detection. In this exercise, the participant may be required to conduct a radiation survey and to define ISO-dose contours for radiation and high-radiation areas. It would involve the selection of proper survey instruments, performance of operability checks, and marking of the defined ISO-dose contours.

2. DEMONSTRATION – PERFORMANCE EXERCISE. This could be described as a walk-through exercise in which the participants perform the operations needed to cope with a particular incident; however, these operations do not occur in real time, but occur step-by-step in rather slow motion. Mistakes are corrected as the participants go along.

3. COMMUNICATIONS AND NOTIFICATION EXERCISE. This is an exercise that involves the use of various pieces of communication equipment and the notification procedures. An exercise of this type is highly recommended because although personnel may think of themselves as being skilled in the use of a two-way radio, they may find that under the stresses of an emergency situation they talk at a rapid rate or even forget to key the mike, causing vital time and information to be lost in the notification process.

4. A SIMULATION EXERCISE. This is an exercise in which the emergency is completely simulated. Another term for this is "paper exercise." A simulated, or paper, exercise can be valuable for the review of emergency plans.

5. A FULL-SCALE EXERCISE. Is one in which a complete incident is planned and in which all the organizations respond.

risk. On the other hand, an announced exercise has the advantage that the participants know what is coming; and rather than have a poor showing, they spend some time planning for it themselves. One useful technique is to announce that the exercise is impending but not give specifics about the type of incident or the date. This arrangement actually is a combination of announced and unannounced exercises. It has the advantages of both, but has the additional disadvantage (as with all unannounced exercises) that the participants get "on edge" and perhaps perform worse than they would in an actual incident.

A key point in the planning of an exercise is to limit its scope. Although an actual incident may involve a number of various emergency-response organizations, all of them may not be participating in the exercise; for example, they may be notified, but their response simulated. To limit the scope of the exercise once the degree of participation is known, develop a flow plan for the exercise. Identify the critical communication points: These are points at which requests for assistance could go inadvertently to a non-participating organization. Plan to isolate the incident by blocking these communication points. There are a number of ways in which this can be accomplished. One, for example, is by requesting that an organization be notified of the exercise while, at the same time, explaining that no response is necessary from that organization.

Determine the starting and ending points for the exercise and what happens between. Establish the event that triggers the exercise. Also plan to control the course of the exercise. This means steering it in the direction needed to accomplish the stated goals. There are certain critical points in the course of an exercise that should be watched closely. Included are those places at which the activities may lag. Here some extra incidents might have to be added to keep the exercise moving. Watch for places at which the exercises might come to a halt; for example, do not let the exercise die for the lack of a phone call that was not made, or do not allow the fires that were built to burn out before the fire fighters arrive. In the last example, it may be necessary to place the call to fire fighters first, to have them respond, and then to ignite the fire, in order that it reaches its peak just at the time they arrive. Leave some room for on-the-spot innovation by the director and umpires; they may have to interject additional exercise problems in order to keep the exercise moving. Finally, establish the exercise end point. The end point is the point at which the exercise objectives have been met.

Writing the script is an essential part of the exercise plan. The first step in writing the script is to develop the scenario, which includes the events that have caused the emergency incident. While the participants may never know until the exercise is over what these events were, they should be listed in order that the planners can create a credible incident. The incident must be credible; otherwise, the participants will not treat it with the seriousness it deserves.

The script should include both the anticipated and the unexpected actions of the participants in order that the exercise can be steered in the direction required to meet the objectives. Some exercises come to a "screeching halt" because the planners underestimate the ingenuity and skill of the participants, who, for instance, may solve the exercise problem easier and faster than planned. This can be a real problem if there are a number of agencies involved. Suppose, for example, that a real fire is used for the exercise: the fire fighters may extinguish the fire much too soon and may clean up the area before other radiological teams arrive, thereby robbing other participants of the opportunity to meet their own objectives. Finally, the scenario should be kept as simple as possible. Although all key points must be included, the scenario must not be overloaded with verbiage.

Since all exercises have some degree of risk, a safety plan must be written for all. As will be discussed later in more detail, realism in the exercise is important; however, the more realistic the exercise, the greater the chance for accidents. An exercise safety plan should be written, therefore, to include all of the potential hazards and the steps necessary for the reduction of these hazards.

Appoint a safety officer who has the authority then to call off the exercise at any time should the participants' safety be unnecessarily jeopardized. Establish a signal to signify a real emergency. Should there be an actual injury during the exercise or a real emergency during the course of the exercise, the signal indicates to everybody that a real emergency response is required. The signal, for example, could be "Mayday" or "conditions red."

CONDUCTING THE EXERCISE

As mentioned before, for maximum effectiveness, the exercise should be as realistic as possible in order to place the participants under the same kind of stress that they would experience in an actual emergency. There are a number of techniques that can be employed to make the exercise realistic. Included are provisions for actual radioactive materials. Another is the use of fire. Many fire departments have burned buildings scheduled to be razed as part of an exercise. This procedure provides a good degree of realism. Another technique involves "vi[illegible]ims" and simulated injuries. These "injuries" must be realistic. Simulated injury kits are available; they make the injuries so realistic that even a doctor or a trained emergency medical technician would have difficulty in distinguishing them from the real thing. This point will be discussed in more detail later.

A key person in the exercise is the exercise director. Since the director has overall responsibility for the conduction of the exercise, the role is much like the director of a play. It is the director's responsibility to steer the exercise in order that the objectives are met and to ensure that the exercise does not drag.

Other key persons are the umpires who watch the exercise and collect the data necessary for the critique. They should have the authority to interject additional problems when appropriate. The duties of the umpires should be detailed in the planning, and umpires should be provided with checklists of important points to observe.

If possible, there should be a communication link between the umpires. Citizens' band radios are useful for providing a clear channel of communications between the umpires. The umpires must be identified. Since the umpires should not participate in the emergency operation, the participants must know who they are. Umpires should keep out of the way and should be as unobtrusive as possible.

Most exercises are plagued with observers, who usually are VIPs who come to observe the exercise. They have a tendency to confuse the participants and sometimes to make the participants nervous to the point that they don't take the actions that they would normally take in an emergency. However, the observers can provide a useful function. They can serve the purpose of bystanders or part of the crowd that would come to watch an actual emergency. All emergencies involve people other than those coping with the situation. One good rule to follow is this: Observers as bystanders can be put to work if they are needed for an emergency situation.

Other individuals who somewhat confuse the situation are the photographers because many emergencies are documented by photography. Photographers can detract somewhat from the realism; however, they serve a useful function, and they must be accommodated. As with the umpires, they should be well identified and as unobtrusive as possible.

Another group consists of role players and victims. Role players are those who play a particular role in the exercise. They usually are clued in before the exercise occurs, and they know exactly what they should be doing; for example, it may be desirable to have someone play the role of a plant manager. The best situation exists when the people play their real-life roles. In the example cited, the services of the real plant manager should be obtained if possible.

High school and college drama classes are good sources of victims. These young people are eager to participate, and usually do an excellent job as victims. Sometimes their acting is so good that the participants are not sure whether or not they have a real emergency. All participants must be told who is liable and what their liabilities are.

Use of Radioactive Materials

In the use of radioactive materials for exercises, the exposure of all participants, role players, victims, and others, must kept to an absolute minimum. Keep an exposure record for each. If actual gamma sources are used, all personnel should wear dosimeters. Also know the location of all radiation sources at all times, and ensure that none of the sources is lost. Appoint a radiological safety officer, who is charged with the responsibility of making sure that no one receives an undue exposure.

Gamma sources can be simulated. Special gamma simulation meters are available through some Civil Defense agencies. They include radio transmitters and special "meters" that receive the radio transmissions. These radio transmissions duplicate gamma radiations, and the meters respond accordingly, reading out in roentgens per hour. Another way to simulate a high gamma radiations field is to place an up-scaled meter face on the survey instrument. In this case, a small amount of radiation appears to be a large amount. This arrangement has the advantage that the meter needle is deflected to full scale (is "pegged").

Alpha contamination is very difficult to simulate. The real thing is best, but is difficult to obtain; however, if actual alpha contamination is used, make sure that it cannot be removed. It should be fixed firmly onto the substrate of the contaminated material. One effective way of simulating alpha contamination is with a fluorescent material; a black light is used in place of a detector.

Public Information

An important aspect of any exercise is public information. It is imperative that the exercise does not cause a panic among the public. People who see the emergency operation may not understand that is is an exercise and may panic. A public information officer should be appointed to ensure that this does not occur. This officer provides the important single source of information, both to the public directly and to the news media.

The value of factual and honest public information in radiation accidents is so important that the following remarks prepared by Mr. Duncan Clark are introduced here. Mr. Clark prepared his remarks for delivery before the Seventh Annual Naval Reserve Nuclear Science Seminar, Brookhaven National Laboratory, Upton L.I. New York on September 18, 1959. At the time, Mr. Clark was the Assistant Director for Public Information Service, U.S. Atomic Energy Commission, now the Nuclear Regulatory Commission. Although Mr. Clark's remarks were presented two decades past, they are both pertinent and relevant for today's handling of public information in radiation accidents. Mr. Clark's speech is reproduced here and continues through page 34 of this module:

PUBLIC INFORMATION IN RADIATION ACCIDENTS

> I have changed my assigned subject from "Public Relations in Radiation Accidents" to "Public Information in Radiation Accidents" for a reason I believe to be important. The term "public relations," rightly or wrongly, has for many people the connotation of attempting to influence people rather than to inform them. This, of course, is not the proper business of a Government agency. The function of a Government in-

formation man is to provide useful facts to the public news media as quickly, as completely and as accurately as possible, and not to attempt to control opinions about those facts.

This may sound as if I were taking a firm stand against sin, but I believe that it also is enlightened self-interest for a Government agency, or a contractor engaged in Government work, to present facts objectively rather than to select or arrange them in an attempt to influence attitude or opinion. The temptation to avoid criticism or embarrassment by telling only part of the story, or by sugar-coating it, can be strong. This temptation, however, should be firmly resisted in connection with any work that is financed by money from the general taxpayer. The embarrassment involved in admitting an error candidly is small compared to that which results if you are caught trying to hide or minimize it, and your attempted evasion is held up before the public. A radiation accident, for example, is an unpleasant fact of life which must be faced up to. There is no public relations magic that can make it fade away, or reduce the legitimate interest of the news media in telling the public about it. The most important idea that I hope to leave with you is that the best way to handle the informational aspects of such an accident is simply to tell the truth about it. The comforting corollary is that the truth about a radiation accident is almost certain to be much less alarming that the exaggerated ideas which will spring up in people's minds if an atmosphere of mystery about the accident is created. Public announcement of the facts will reduce public alarm and increase public understanding. In other words, good public information practices beget good public relations.

I have been in the Public Information Service of the Atomic Energy Commission since early 1952. My work has given me a good vantage point to observe the public reaction to the radiation accidents which occurred during that time, and to try to figure out why the public reacted as it did. I am tempted to postulate that there is an inverse relationship between the magnitude of an accident and the public reaction to it; in other words, the less serious the accident, the more intense the public concern. I suspect that this is not really an unnatural law, but it has been startling at times to see how much alarm has been aroused by a relatively minor accident and, on the other hand, the calm with which some relatively serious ones have been accepted. In the course of these remarks, I hope to suggest some of the reasons why little can cause big headings, and how to keep them in perspective.

The public information handling of an emergency situation is part of the whole complex of decisions which must be made to meet the emergency. These decisions affect each other. An unwise operating decision inevitably will make the public information task more difficult. Conversely, poor information procedures can cause serious interference with measures necessary to alleviate the emergency.

The decisions involved in any crisis are difficult. Actions must be performed quickly and under extreme pressure, yet the consequences of poor judgment are likely to be very serious. Normal procedures must be shortcut or abandoned. Confusion is paramount – it is hard enough to ascertain the facts, let alone to decide what to do about them.

All of these difficulties are compounded several times over when radioactivity is present. I am sure that such operational decisions as how to care for casualties or whether or not an area should be evacuated must be greatly complicated by the presence of radioactivity. Similarly, the public information problems are made much more difficult. For one thing, many people do not react at all rationally when the word "radioactivity" is mentioned. This is not necessarily to their discredit. Radioactivity still is a new and mysterious phenomenon to most people. The very fact that it cannot be detected by the unaided senses makes it more frightening. It is inevitably associated with nuclear warfare, and the fears and anxieties concomitant with life in this shifting and uncertain world, in which science seems to many to be an evil genie rather than a helpful servant, find a focal point in the specter of radiation. A few months ago, a public opinion research group reported on the results of a nationwide survey of teen-agers to determine their attitudes toward atomic energy. Nearly all of them associated it with warfare rather than peaceful applications. Ninety percent of these young people said they expected that nuclear energy eventually would destory the human race. Only 39 percent said they were glad nuclear energy had been discovered. The atomic energy industry had achieved a remarkable safety record, but the relatively few accidents which have occurred have assumed exaggerated importance because of such emotional reactions. Fears about fallout have added fuel to the flame. What are the connotations of radioactivity in the public mind? Mysterious, invisible danger, striking without warning, causing death or dreadful illness, premature aging, sterility and the malformation of children through many generations. As a result, primitive, almost instinctive fears are awakened by this new force unleashed by modern sciences. No, it is not surprising that people are afraid of radioactivity.

The aura of almost superstitious fear surrounding radioactivity greatly complicates all aspects of meeting a radiation emergency. Recognition of this fear also points toward what is perhaps the most important and most difficult part of the public information task. This is the work that is done, not after the emergency actually has occurred, but in the months or even year preceding it. It is the work of public education.

Despite our level of technology, most people in this country today would have a hard time explaining how an electric motor works. I know that many people drive an automobile daily with only the most rudimentary idea of what makes it go. Thousands of people entrust their lives to airlines without any understanding of how something heavier than air can fly. Yet, most people are not unduly afraid of electricity or gasoline engines or airplanes because they have a good idea of the magnitude of the risks involved in their use, even though they may not understand the principles involved.

Similarly, we don't need to turn ourselves into a nation of nuclear physicists to achieve adequate public understanding of radiation hazards and the safeguards against them. What is chiefly necessary is to bring people to the understanding that radiation should not be thought of in simple black or white, "is" or "is not" terms, but rather in such relative terms as "how much", "what kind", "at what rate" and "for how long." When people are capable of grasping the quantitative nature of radiation hazards, rather than believing that the mere presence of any amount of kind of radiation is deadly, they will have gone a long way toward viewing the hazard in proper perspective.

If a radiation accident occurs at a particular facility, the reaction of the local public will depend to a considerable extent upon whether or not they have previously been exposed to a public education program about radiation. Educating the public in a new technical field is a long, slow process. No single Government agency or private organization has the resources to conduct the massive campaign which would be necessary to make a deep and lasting impression on the public consciousness. Many millions of dollars are spent by advertisers each year on such relatively simple tasks as promoting the sale of a particular brand of soap or cigarette. The task of educating the public about radiation is much bigger and more difficult. Private firms engaged in nuclear energy projects, or using radioactivity in one way or another, can assume part of the job. Some are doing so, and I hope that eventually every firm using radioactivity will recognize that it is simple self-protection to educate its local public before an accident occurs, rather than to engage in frantic and probably ineffectual reassurances after the fact.

An important part of the educational job must be taken on by volunteers. By this I mean people like yourselves. Every time you make a speech before a local Chamber of Commerce, Lions Club or school, and every time you take the trouble to explain the facts of radiation to a newspaperman or magazine writer, you are performing a real public service.

It is a mistake to be critical or contemptuous of the average newsman because of his lack of knowledge of your field. A good newsman is eager to learn and has the same respect for facts that a scientist has. But until recently, specialists were a luxury that only a few metropolitan newspapers thought they could afford. Fortunately the situation is changing, although there is still a long way to go. The September 1959 issue of The Quill, the magazine of the professional journalistic fraternity, Sigma Delta Chi, states in an editorial:

> A generation ago any reporter worth his salt was confident that he was competent to cope with whatever assignment came his way, whether it was a general alarm fire, a juicy murder, or interviewing the latest literary lion.... A good reporter could take all types of assignments and come up with a story that would pass muster on the city desk....
>
> In that day only the great metropolitan newspapers could afford the luxury of a...full-time specialist in any field. Today, even in the smaller communities, it is just as true that a paper cannot afford to be without specialists in at least some fields....
>
> It is an acute problem for the metropolitan paper, even with all its resources in manpower and money. It becomes a more difficult problem on a smaller paper where both manpower and financial resources are limited. Yet it must be solved if the press is to continue to fulfill its function of informing the people and helping them understand the significance of the news....

In almost any community near a plant or laboratory where radioactivity is produced or used, there are likely to be one or more bright young newsmen eager to learn something about atomic energy. If there are enough of them, news seminars can be held with profit. In such education sessions, the newsmen not only should be given general information about radioactivity, they should also be briefed as candidly as possible on the possible radiation hazards at the particular facility and the safeguards taken against these hazards. Properly handled, such briefings can be reassuring rather than alarming. I repeat that the facts about radiation are less frightening than the specters conjured up by imagination.

I have devoted so much time to public education before an accident occurs because I believe it is at least as important as, or possibly more important than, the actions taken after the accident happens. Now, let us assume that neither the local public nor the local news media knows much about radiation hazards, since this probably would be the case.

Various kinds of radiation accidents are possible, of course. The accident may occur in a Government facility, a contractor facility, or a privately owned and operated facility. It may occur during the transport of radioactive materials by truck, train, plane or ship. There may or may not be a release of radioactive materials to the environment. The public may or may not be exposed to hazard.

From the public information point of view, the simplest radiation accident is one restricted to the public. In such an accident any people involved are on their regular working premises, and familiar routines and procedures will be applicable to some extent. Also, since the accident is inside the installation, the officials involved have unimpeded opportunity to prepare to make the accident public in proper perspective. Public hysteria is not likely to occur when it is made obvious that the public is not endangered.

This kind of accident, however, sets a dangerous public information trap for shortsighted management. Since the accident is not immediately apparent to the public, there is a temptation to sweep it under the rug and not announce it. It is very easy to produce all sorts of rationalizations against announcing a radiation accident. No one may have been seriously hurt, and no radiation overexposures may have occurred. Of course, some judgment must be exercised; there is no point in issuing an announcement every time there is a laboratory spill. Nevertheless, I am convinced that the surest way of turning a minor radiation accident into a major one, through speculation and rumor, is to fail to announce it fully and promptly. This is true particularly if a reactor is involved.

Any significant mishap to or malfunctioning of a reactor, whether or not radioactivity is released, is news today and in the foreseeable future. There are a number of capable and determined reporters covering the atomic energy program, and sooner or later one of them will hear about it. It does not matter then how innocent may have been the intentions of the people who decided not to make the announcement. Their motives immediately become suspect, and an aura of mystery and concealment is thrown about the accident, and it lands on the front pages as a sensationalized disclosure. Since even minor accidents may have aspects which make them newsworthy, it is best to obtain the counsel of experienced public information officials before deciding whether or not one is significant enough to be made public.

Of course, many accidents occur under circumstances which make them known to the public almost immediately. For example, a truck carrying radioactive materials may overturn on a public highway. An explosion may occur in a plant in or near a populated area, under circumstances which require that local fire and police departments must be called into action. In such instances, the news media and the public quickly become aware that an accident has occurred and they have a totally erroneous initial impression of the public hazard. This erroneous initial impression will spread like wildfire unless immediate action is taken to counteract it. There is risk that panic among the public will cause more serious hazards than the accident itself, and will interfere with the measures necessary to bring the emergency under control. An even more extreme situation would be an accident involving genuine hazard to a local population, such as release of significant radioactivity to a populated area. No major radiation accident of this nature has occurred in this country, and we all know that the possibilities of one are extremely small. However, it is apparent that plans must be made to meet even such remote possibilities.

The closest we have come to the public information problems which would be created by an accident of this nature was a situation which actually involved no significant radiation hazard at all. This was the explosion of a thorium compound at the Metallurgy Laboratory of Sylvania Electric Products, Inc., at Bayside, Long Island, on July 2, 1956. This accident did not cause any public hazard, and it did not create significant radiation hazard even to the employees of the plant. Nevertheless, for some hours many thousands of people had the impression that a major radiation accident, involving possible hazard to the public, had occurred. For this reason, the Sylvania accident is the best case history we have to indicate the public information problems which would accompany a serious radiation accident involving possible hazard to the public. It also illustrates the factors which tend to magnify an accident to many times its proper size simply because of the real or imaginary threat of radioactivity.

As you probably recall, the Sylvania accident occurred when plant employees were engaged in burning thorium material for conversion to oxide. An explosion occurred when a small piece of the thorium material was placed under a burning hood. This was followed by one or possibly two other explosions. Physical damage was largely confined to the room in which the men were working, and was estimated at about $25,000. Nine employees were injured, four seriously enough to be hospitalized. One of these men later died. The injuries were from blast and burns, and there was no serious radiation exposure or ingestion of radioactive materials. Outside the building, there was no detectable radioactivity above background.

The accident occured at 8:40 a.m. By 9:30 am., there were four complete TV newsreel crews, 15 newspaper and wire service reporters and 10 news photographers at the site, and news aircraft were overhead, taking aerial photographs. Telephone inquiries from news media were pouring into the Commission's New York Operations Office, and several reports had arrived at the Office to cover that end of the story. At about 10:30 a.m. one of the radio-TV networks advised the New York Operations Office that its switchboard was jammed with calls from Bayside residents asking whether or not they should evacuate the area.

The Commission's New York Operations Office and the Sylvania Company did a fast job of getting known facts to the public. At 9:15 a.m., 35 minutes after the accident, a statement was issued that it was non-nuclear in nature. An hour and a half later, it was announced that no radiation hazard existed outside the building in which the explosion had occurred. At 1:30 p.m., it was announced that the material involved was thorium, and it was emphasized that thorium is only mildly radioactive and has been used in non-atomic industrial processes for many years. AEC and Sylvania officials stated that there was no danger of radioactivity outside the plant and that any contamination inside was negligible.

Despite these reassurances, the afternoon papers in the New York area carried banner headlines on the accident. Typical ones – in type two inches high – were: "300 Tested for A-Blast Poison," "Blast in Queens Atom Lab," and "Blast Rocks Queens A-Lab, 9 Hurt, Rays Hit 45 Firemen".

Nearly all of the initial stories emphasized the threat of radioactivity. Typical statements were that the danger of contamination "was so acute" that specialists from the New York Health Department's radiological unit were dispatched from Manhattan, that 45 firemen had been contaminated, that firemen and Sylvania employees would undergo hospital tests to determine whether they had suffered radiation effects, and that more than 300 people had been exposed to radioactivity.

Before one criticizes the newspapers for this treatment of the accident, it should be recognized that the news stories were not figments of the reporters' imaginations, but were based on information which had been given to them. For example, reporters learned that soldiers had been sent from nearby Fort Totten to help control the emergency, that 10 doctors had been sent to the scene by the Army and Navy, that radiological experts had been dispatched by the Atomic Energy Commission and the New York Department, and that the 300 employees in the building had been directed to go home, bathe thoroughly and report later to company physicians for medical examinations. Fire officials said that 45 firemen had been contaminated in one degree or another, and that they would be tested for radioactivity. Four firemen and more than 20 policemen were hospitalized for observation. Work clothing of employees was collected after the explosion, and employees who had left the site were instructed by telephone or telegram to bring clothing in. The lunch for Sylvania employees, which was in a building about 200 yards from the explosion site, was thrown away. Policemen cautioned mothers in nearby residential areas to keep their children inside.

Reporters could not ignore these actions – they were a legitimate part of the story. Undoubtedly this flurry of official activity gave the reporters the impression that a big story had broken, and that significant radioactivity had been released. Straightforward reporting of what was happening at the accident scene could hardly help but give the public the same impression.

Along with facts of the kind mentioned above, the news stories also carried the reassuring information provided by the AEC and by Sylvania. As a result, the stories had contradictory elements: they included official statements that there was no significant radiation hazard, and at the same time reported official actions that inevitably gave the impression that such a hazard did exist.

Remember that the job of a reporter covering a spot news story is to report, not to interpret or select facts. He will go to various sources which are considered to be authoritative, and will report what he is told by such sources, even if some of the statements appear to be contradictory. He will also report what he sees as well as what he is told. This is his job, and there is no reason to criticize him for doing it.

Even though the public undoubtedly received an exaggerated impression of the Sylvania accident on the day it happened, the quick action to report the facts as candidly as possible had the healthy effect of making the story a one-day wonder. The stories the next day were entirely different in tone. Typical headings were: "Doubt Radiation Hurt A-Victims; Queens Workers Will Undergo Checkup to Reassure Them"; "No Radiation Peril in Labs, N.Y. Area Told; Installations Cannot Release Dangerous Amount, AEC Says," "AEC Denies City Faces Radiation," and "Firemen Unharmed in Blast, AEC Says." If the AEC and the company had not provided information as quickly and as completely as possible, I am sure the story would have built up rather than decreasing in news value.

Since the Sylvania accident occurred, there have been two radiation accidents which involved much more serious radiation exposures, but which received much less sensational treatment by news media. One was the Y-12 accident at Oak Ridge, in which several persons received significant doses of radiation. The other was the accident at Los Alamos Scientific Laboratory, which resulted in the first radiation fatality in the Atomic Energy Commission's history.

As I said a few minutes ago, the handling of accidents in remote, relatively self-contained installations is simpler in some ways than coping with a situation such as the Sylvania accident. This is part of the reason for the sound, unsensational news treatment of the Y-12 and Los Alamos accidents. Both of these accidents were in localities removed from an active metropolitan press. Also, they did not involve fire or other physical damage which would have required the presence of local authorities. As a result, there was only one source of official information and reporters were not present at the accident scene. Nevertheless, if information on these accidents had not been issued promptly and candidly, there is little or no doubt that they would have ultimately reached the public as sensational disclosures or suppressed information. In each of these accidents, the news media felt that they were being dealt with straightforwardly, and that the facts were being given them as soon as they were obtained. As a result, they wrote their stories factually, and did not attempt to build up an atmosphere of mystery or charge that facts were being withheld.

There have been several other radiation accidents which are interesting from the public information point of view. Examples which come immediately to mind are the M.W. Kellogg Co. accident in Houston, Texas, in which several employees were exposed to radiation and in which radioactive materials were tracked into several homes, and the incident in Connecticut which involved the picking up of a cobalt-60 radiography source by an employee. Both of these incidents had dramatic story elements and involved the possible exposure of the public to radiation. As a result, they received extensive coverage by news media and both were dramatized on nationwide television programs. These accidents are of interest to the Commission because they point up the problems involved in informing the public about radiation accidents in facilities which are privately owned and operated, but which are licensed by the Commission to handle radioactive materials. Obviously, the Commission has the responsibility to provide certain information to the public about such incidents, but the Commission's public information responsibilities are modified when incidents occur in facilities which are privately owned and operated. We have given considerable thought to the problems resulting from such incidents. I am not going to analyze them in detail here. Rather, I would like to make some generalizations which I believe apply to the public information handling of virtually any kind of radiation accident.

1. The news media treatment of an accident, and the public reaction to the accident, depend to a considerable extent upon what has been done before the time of the accident to educate the public about radiation in general,

and about the specific hazards of the particular operation and the safeguards taken against them.

2. An important aspect of this educational effort is the informing of local news media and of local authorities. Local firemen and policemen should be made aware of the potential hazards at the installation, and also should be advised what hazards are not present. For example, if no serious radiation hazard can be expected from the materials involved in a certain operation, the local authorities should be aware of this so that they will not unduly alarm the public by taking unnecessary precautions in the event of an accident. It should be remembered that the statements of local authorities will have an important influence on the news treatment of an accident. Reporters are accustomed to working with the local fire and police officials, and they will naturally go to them for information.

3. A disaster plan should be worked out in advance. It should cover much more than just the public information aspects of the emergency, of course, but the public information aspects should be an important part of the overall plan. The advance planning should include determination of the hazards to be expected in the event of accident, and what can be said publicly about them. It could even include the advance preparation of "canned" statements for use under certain circumstances.

4. Get the information out as quickly as possible and as completely as possible. If classified information is involved it must not be compromised, of course, but classification should not be used improperly to avoid giving out embarrassing facts or as dishonest justification for less than adequate statements. It is better to admit an error than to be forced to confess it under the pressure of newsmen's disclosures.

5. Work with the reporters, not against them. Remember that they are very likely going to get a story whether you like it or not. If the responsible officials will not give them the facts, they will go to other sources. In the absence of official information, they will be forced to reflect rumors and exaggerated or distorted information, or they may speculate. An accident is an unpleasant fact of life. There are no known public relations techniques that will make it disappear, or reverse time and make it unhappen. The best that can be done is to face the facts and strive to keep the news stories and the public reaction in proper perspective.

6. Be sure of the facts before they are issued. Do not be drawn into making statements that may have to be retracted later on. Avoid being led into speculation or comment on hypothetical situations. In the early hours of an accident, many facts will not be known. This should be stated in response to reporters' questions, and the reporters should be assured that additional information will be provided as quickly as possible.

7. Remember that the really fast media are the radio and television stations. In any major accident, they are likely to be on the air with whatever information they have hours before the first newspaper accounts appear. The early public reaction to the accident will be molded chiefly by the radio and television broadcasts, and it is vital to get information to these media to prevent undue public alarm.

8. Make sure that the information issued publicly is consistent. The best way to achieve this is to have only one spokesman in dealing with the news media, and only one point of primary issuance, unless reliable coordination of more than one spokesman can be accomplished. If an experienced public in-

information office is available, the information should be channeled through him, although he may find it advisable to call upon operating officials to appear at news conferences under certain circumstances. Keep information flowing to the spokesman; he can serve an important function by minimizing undue public alarm and also by keeping reporters out of the way of the people handling other aspects of the emergency. Make sure that the local officials are receiving at least as much information as the news media, and not later than they do. It may be advisable to issue all information through the local officials; they are likely to be known and trusted by the local news media. On the other hand, it may be necessary to issue statements supplementing those of the local authorities.

9. If the accident is away from the normal issuance point for news, keep communications between the accident site and your home installation. It may be necessary to issue information not only at the accident scene, but at another point more accessible to the news media. In such circumstances, make sure that the same information is being issued at both places.

10. Remember that any action taken during any emergency may be reported publicly and may have considerable influence on the news treatment of the accident. Of course, necessary actions will have to be taken whether or not they produce bigger headlines. However, the possible public reactions should make the operating officials weigh each action carefully before proceeding, to make sure it is really necessary. In any radiation accident, the tendency probably will be to take extra precautions to protect health and safety, and it should be made as clear as possible to the news media that these are precautionary measures and do not necessarily mean that an actual danger is present.

11. Whenever possible, it is best to rely on the judgment of experienced public information officers. If possible, they should be part of the initial team reaching the site of an accident. If they cannot be at the site, they can probably be reached by telephone. It is true that public information is an art, not a science, but an experienced information man knows news media needs, can judge news media reactions, and will act correctly almost by instinct most of the time, whereas an inexperienced person could do the wrong thing just as instinctively.

The Atomic Energy Commission has given responsibility to eight of its Operations Offices to provide radiological assistance in the event of a radiation accident. These Operations Offices have established radiological assistance teams which would respond to accidents in specified areas. Each office has drawn up a radiological assistance plan, and each plan has a section on public information. These sections are generally consistent with the principles I have stated above.

In addition to responsibilities for assistance in the event of accidents involving the peaceful uses of radioactive materials, the assistance teams are included in a nationwide network established by the Albuquerque Operations Office of the Commission to handle accidents involving nuclear weapons. The Department of Defense also has established a system of teams for weapons accident emergencies.

As you probably know, the AEC and DOD have issued an information bulletin on atomic weapon accident hazards, precautions and procedures. This bulletin has been widely distributed to local police and fire department officials, to state officals, to military field commands and to the news media. The bulletin explains that stringent safety measures are taken in the design and transportation of atomic weapons, and states that they are designed to preclude a nuclear explosion in the event of

> an accident. It points out that the probable hazard from nuclear weapons accidents is commensurate with the hazard from conventional weapons and materials, and would consist chiefly of the possible detonation of high explosives and the possible release of plutonium. The bulletin states that safety restrictions have been placed on the number of atomic weapons per shipment, so that the plutonium inhaled from an accident would not result in serious injury. It describes procedures for the notification of the proper authorities in the event of a weapons accident and describes emergency actions to be taken.
>
> Issuance of this information should help to prevent undue alarm in the event of a weapons accident. The local authorities should be aware that the principal hazard would be from conventional high explosives, and not from a nuclear detonation. Classification rules would present the issuance of many details about the accident, but information on the degree of public hazard almost undoubtedly could be released in unclassified form. There is no question that such an accident could create considerable local public alarm. However, any weapons accident will quickly bring into action a detailed plan for meeting all aspects of the emergency, including the informational ones, and there is no necessity for me to discuss the problems in further detail here.

I hope that I have given you some feel for the public information problems which will arise in the event of a radiation accident, and an indication of some of the ways to meet them. Obviously, it is a lot easier to make a speech about what to do than it is to do it in a real emergency. The essence of an emergency is that things do not go smoothly or in accordance with routine. Procedures must be modified to suit the circumstances, and there just is not time to do everything that should be done. However, the following of sound public information principles can make it easier to bring the emergency under control, can prevent unnecessary and possible dangerous panic, and can help to prevent public repercussions which could be more serious than the radiation accident itself.

Critique

The critique can be one of the most difficult phases of an exercise. If not properly handled, it can lead to delicate situations between the participants. If the critique is a mass meeting that involves all the participants, it may end up in faultfinding and fingerpointing. The participants may be under a certain amount of pressure and tension, and they may attempt to justify mistakes and mix-ups by claiming that the exercise was unfair. Or they may blame other groups for causing events that led to the mistakes. For the participants to be objective about their own actions is understandably difficult.

In any event, it is desirable that the umpires have a separate critique meeting to allow for a more frank and candid atmosphere.

The critique should result in a list of corrective actions. Some of these corrections can be made immediately without much effort. Others may require considerable time and, perhaps, an expenditure of money. In either case, someone should be assigned specific responsibility for each of the corrections. They should be given deadlines and a specific person to whom to report. This arrangement reduces the chances that the needed corrective actions will "fall into a crack."

Documentation

There are numerous ways in which an exercise can be documented. Each has its advantages and disadvantages. Movies, for example, are one way in which the exercise can be documented, although movies are expensive and can be made of all exercise points only with difficulty. If a thorough job of filming an exercise is done, it results in many feet of film that contains much irrelevant material. Occasionally, a documentation film is made about the exercise; the purpose of this film usually is to explain to others what occurred. In most cases, such films are not of much value to the participants. On the other hand, videotaping of the exercise can be of extreme value to the participants; the instant-replay capability permits participants to observe instantly their own actions. They can observe their own mistakes and quickly make corrections.

Photographs and slides, like movies, are good for describing the exercise; however, their value is limited as a means of recording mistakes.

Regardless of the techniques used, a written report should be made. This report should contain the details of the exercise, including the planning, the script, the scenario, and whatever corrective actions were taken.

Conclusion

Exercises are a rewarding method with which training and experience in emergency handling can be provided. Although most people enjoy the challenge of an exercise, there is a minority that reacts with anger to it. They resent being placed under pressure while being observed by others, possibly including their supervisors. Nevertheless, most people seem to have fun during exercises and to take the exercises seriously.

EXERCISES

1. Prepare a one- or two-page summary of the Duncan Clark presentation, "Public Information in Radiation Accidents."
2. Explain the importance of the scope of an exercise.
3. Discuss the steps in the planning of an effective exercise.

MATERIALS

None.

PROCEDURES

A SIMULATED EXERCISE FOR COPING WITH AN EMERGENCY SITUATION

1. Assume that you must cope with the following emergency situation:

> You are the reactor supervisor on duty at a research facility. Research personnel are performing radiochemical analysis of irradiated samples in a radiochemistry laboratory located three floors below the reactor control room. You have live and direct communications with the laboratory, and you hear what sounds like an explosion. The researchers fail to respond to your attempt at communicating with them.

2. Prepare an outline for coping with this situation. Cover all the required points.
3. Under instructor supervision, conduct a group discussion about this situation.

DATA TABLE

None.

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TEST

1. Why have emergency drills and exercises?

2. Discuss the advantages/disadvantages of conducting an unannounced exercise.

3. Describe the responsibilities of the public information officer. Include a list Do's and Don'ts.

4. Describe the responsibilities of the exercise director. Include an outline of tasks to be performed before, during, and after completion of the exercise.

NUCLEAR TECHNOLOGY

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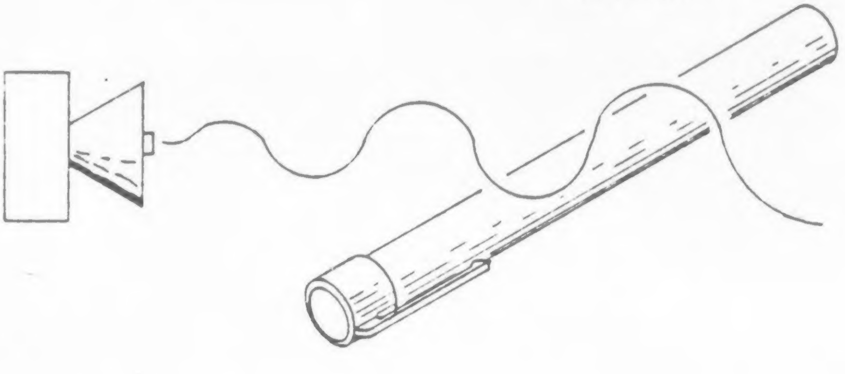
RADIOLOGICAL EMERGENCIES

COURSE 18



CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

NUCLEAR TECHNOLOGY SERIES
INDEX
for
COURSE 18, RADIOLOGICAL EMERGENCIES (SEVEN MODULES)

NOTE: Each module in this Course is numbered separately, and the page numbers begin with page 1 in each module. Therefore, this Index lists for each entry the module number (underlined), followed by a comma and the page number. Figures and tables are listed by their numbers, followed by the module and page number in parentheses. A Master Index is available in a separate volume. This general index merges all index entries from the 35 Nuclear Courses. It is a valuable research tool, with which the student or researcher can locate all the references to any subject within the 35 Courses.

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